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THE REACTIONS OF NECTURUS TO STIMULI RECEIVED THROUGH THE SKIN

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INTRODUCTION

The mud puppy, *Necturus maculosus* (Rafinesque), of the fresh waters of North America has long been of interest on account of its primitive structure and its systematic position near the base of the amphibian line, but its reactions have been little studied.

For over two centuries it has been known that fishes possess various highly specialized sense organs in the skin, and later work along this line has been done by Herrick ('03), Parker ('09, '10), Sheldon ('09), and Reese ('12). During recent years the reactions of amphibians have been studied by Torelle ('03), Parker ('03), Cole ('07), and others, but upon Necturus very little has yet appeared. Reese ('06), and Pearse ('10) have worked upon the reactions of Necturus to light and heat. Reese found that though all parts of the body could be stimulated by white light, the head was the most sensitive region. He also worked with light passed through "red" and "blue" glass, and found that slow responses were thus induced. In his heat experiments he found Necturus to be sensitive to considerable changes in temperature. Pearse showed that Necturus is negatively phototropic and that it comes to rest in shaded areas. Both the skin and eyes act as photoreceptors, and the stimulation of either brings about negative reactions.

The present study endeavors to ascertain the sensitiveness of the general body surface of Necturus to touch, chemicals, heat, and light.

The experiments were performed on four individuals of average size, though only three of them were used for the light and heat experiments. Just before each experiment the individual to be used was transferred from the aquarium tank into a zinc tray, three by one and one-half feet. The transfer was made by grasping each animal just behind the front legs. The method of measuring movement employed in the experiments was a rather simple one. A coarse wire screen that covered the tray was divided off with twine into inch squares. It was possible in this way to observe and at the same time measure the movements of Necturus beneath the screen.

When not being used for the experiments the animals were kept in running water in an aquarium tank, six by three feet, in the vivarium of the Biology Building, University of Wisconsin. The tank was divided into four compartments, one for each animal. Bricks and strips of wood were used to make suitable dark nooks like the natural haunts of Necturus.

This work was accomplished under the direction of Professor A. S. Pearse, for whose helpful suggestions and encouragement it gives me great pleasure to express my appreciation.

REACTIONS TO TOUCH

The whole outer surface of Necturus is open to stimulation from a deforming pressure, that is, it is sensitive to touch. Animals were tested for touch sensitiveness with wood, glass, and a soft brush.

A blunt piece of wood the size of an ordinary pencil was touched gently to various regions of the body. When any portion was stimulated, there was a forward movement of two or three inches. The nostrils, gills, and tail were the most sensitive regions. Stimulation with a glass rod induced similar reactions as were noted for wood. Stimulation with a soft brush, however, induced no locomotion. The tail and feet were drawn close to the body when stimulated; the gills closed, and when the nostrils were touched with the brush, there was at first a backward jerk, but further stimulation produced no reaction.

In stimulating the ventral side of the body, the mouth region and the tip of the tail were found to be most sensitive. When either of these regions was touched, locomotion followed, but the response was slow. The gills and feet upon stimulation were drawn close to the body. No other regions of the ventral side were sensitive.

Experiments were next performed to ascertain if the nerve endings fatigued by chemical stimuli would react to tactile stimuli. Necturus was stimulated over its entire body with ten per cent hydrochloric acid until it ceased to respond. A blunt point was then used to induce tactile response, but very little reaction followed. The same experiment was tried after sulphuric and nitric acid of the same strength. It was found that there was more response to tactile stimulation after Necturus was fatigued by hydrochloric than after sulphuric or nitric acids.

In performing the touch experiments several points worthy of note were observed:

1. Necturus is nowhere as sensitive to a blunt as to a sharp instrument.
2. When the mouth region was stimulated the head was jerked backward.
3. The regions of greatest sensitiveness are the nostril region, gills and tail.
4. When the gills were touched their movement ceased, but when the wood, glass or brush was removed their motion went on at an increased rate.
5. When the tail was stimulated it was curled up. It was most sensitive at the tip.
6. When the hind legs were stimulated they were drawn backward under the body, while the front legs started to walk.
7. The dorsal region between the legs was the least sensitive of all.

REACTIONS TO CHEMICALS

For testing the effect of chemicals on the skin, the surface of the body of Necturus was divided into seven regions, selected mainly for the different responses that result from their stimulation. They were the regions of the nostrils, head, gills, pectoral girdle, pelvic girdle, back, and tail. With each solution used all the regions were tested with each concentration, and the time given for reaction was always the same, fifteen seconds. If no response was made during the period, it was recorded as no action. The location of the regions are shown in figure 1.

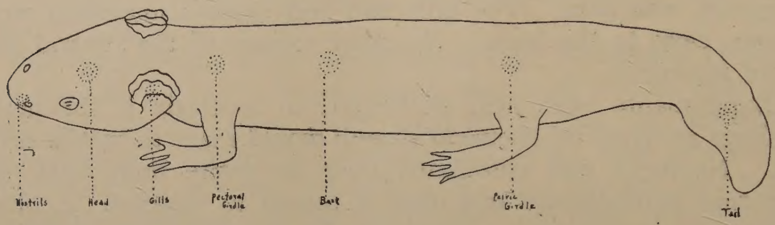

FIG. 1. Outline of *Necturus maculosus,* showing the regions stimulated in the experiments

The substances used in the work were hydrochloric, sulphuric, nitric and acetic acids; potassium hydroxide, ammonium hydrate, magnesium chloride, magnesium sulphate, alcohol and clove oil. In the experimental work all of these solutions were gradually diluted until the limit of reaction was reached. Sufficient time was given between tests at different degrees of concentration and with different substances to eliminate after effects.

The solutions were applied by means of a pipette and were ejected slowly with the tip of the pipette held about two millimeters from the skin. In all cases the animal was completely covered with water during the experiment.

(*a*) *The Reactions to Acids*

In tables I to XI are given the reactions of Necturus to the four acids used. Necturus responds to acid stimuli by locomotion or by a movement of the regions stimulated. If the acid is strong, locomotion takes place; if it is weak, local response is induced. Necturus is most sensitive to nitric acid at all concentrations and hydrochloric gives the weakest response, except acetic. The reactions were found to become weaker and fewer as the acid was diluted. The gills were in nearly all cases the most sensitive region, with the nostrils, head, and tail following in order. Stimulation of the nostril with a ten per cent solution usually produced an expulsion of air from the nostrils and mouth in addition to locomotion. The limit of reaction for hydrochloric, sulphuric and nitric acids was 0.015 and for acetic 0.01 per cent.

TABLE I*

REACTIONS TO 10% HYDROCHLORIC ACID

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 9	B F 14	X F 15	F 3	Squirm	Squirm	Switch tail F 9
II	B F 14	B F 15	X F 14	Squirm	Squirm	Squirm	Switch tail F 15
III	F 15	B 7	F 14	F 3	Squirm	Squirm	Switch tail
IV	B F 7	B 7 F 8	F 13	F 7	0	0	Switch tail F 17
Average	11.2	12.7	14	3.2	0	0	10.2

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* *Explanation of the Tables.*—For convenience, several signs have been employed in the tables. They indicate as follows: F, forward; B, backward; X, animal turned around; O, no reaction. A letter not followed by a number indicates a very slight movement, such as a jerk. The numbers I, II, III and IV indicate the four individuals under experiment. The reactions are noted for seven regions of the body, as indicated at the top of each table, making a total of twenty-eight reactions of four individuals in each concentration. The reactions are measured as inches of locomotion, as described elsewhere, and the average is for total movement, backward and forward, for each region stimulated.

TABLE II

Reactions to 0.1% Hydrochloric Acid

Individual No.	Nostrils	Head	Gills	Tail
I	B 1	B 2	F 14	0
II	B 4	B 2	F 14	F 6
III	B 3	B 2	F 12	0
IV	0	0	F 12	Switch tail
Average	2	1.5	13	1.5

TABLE III

Reactions to 0.09% Hydrochloric Acid

Individual No.	Nostrils	Head	Gills	Tail
I	F 2	Head moved	Head moved	0
II	B $\frac{1}{4}$	0	Head moved	0
III	F 3	Head moved	F 4	0
IV	F 4	F 3	F 3	Curled tail
Average	2.2	.75	1.7	0

TABLE IV

Reactions to 10% Sulphuric Acid

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	F 24	B 13	F 24	F 13	Switch body	Switch body	Switch tail F 10
II	B 2	B F 14	Moved in place	F 14	Switch body F 7	X	Tail curled
III	F 14	F 4	F 24	F 14	Switch body	F 14	F 14
IV	X F 15	B 15	F 14	F 10	F 10	F 7	F 12
Average	13.7	14	15.5	12.7	4.2	6.6	9

TABLE V

Reactions to 0.1% Sulphuric Acid

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 5	B 4 F 6	F 7	F 4	0	F 3	F 5
II	B 3	F 2	Head moved	B 2	0	Moved in place	0
III	B F 8	Moved in place	F 7	F 6	0	F 4	F 4
IV	B F 7	F 7	X	F 7	0	F 5	F 5
Average	5.7	4.7	5.2	4.7	0	3	3.5

TABLE VI

Reactions to 0.09% Sulphuric Acid

Individual No.	Nostrils	Head	Gills
I	B	F 3	F 3
II	B 1	0	0
III	B	F 2	F 2
IV	B 2	0	B 2
Average	.75	1.2	1.7

TABLE VII

Reactions to 10% Nitric Acid

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 4	F 10	F 22	F 16	F 14	F 14	Switch tail F 14
II	B 7	F 8	F 14	F 14	F 8	F 12	Tail curled
III	B 5	F 20	F 14	F 15	F 10	F 15	F 14
IV	B 5	F 15	F 22	F 10	F 8	F 10	F 14
Average	5.2	13.2	18	13.7	10	12.7	10.5

TABLE VIII

REACTIONS TO 0.1% NITRIC ACID

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 4 F 6	F 4	0	F 2	0	0	F 3
II	B 4	F 4	F 7	F 2	F 1	F 5	F 6
III	B 3 F 10	F 6	F 10	F 5	F 3	F 3	F 4
IV	B 1 F 6	F 10	F 3	F 3	F 4	F 2	F 4
Average	8.5	6	5	3	2	2.5	4.2

TABLE IX

REACTIONS TO 0.09% NITRIC ACID

Individual No.	Nostrils	Head	Gills
I	B 2	Moved in place	F 5
II	B 2	Moved in place	F 6
III	B 3	0	F 4
IV	B 1	Moved in place	F 2
Average	2	0	4.2

TABLE X

REACTIONS TO 1% ACETIC ACID

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 3 F 5	B 1	F 6	0	0	0	0
II	B 3 F 6	F 3	F 6	F 3	0	F 1	Tail curled
III	B 2 F 12	B 2 F 6	B 6	B 6	0	F 3	0
IV	B F 14	F 10	F 22	F 10	0	F 4	Tail curled
Average	8.7	5.5	10	4.7	0	2	0

TABLE XI

REACTIONS TO 0.05% ACETIC ACID

Individual No.	Nostrils	Head	Gills
I	B 1	Moved head	F 2
II	B 2 F 3	F 1	Closed gills
III	B 1	F 2	F 1
IV	B 1	F 1	F 2
Average	2	1	1.2

(*b*) *The Reactions to Alkalies and Alkaline Earth Salts*

The reactions of Necturus to alkalies are given in tables XII-XV. Potassium hydroxide and ammonium hydrate did not produce as definite responses as did the acids. The different regions of the body varied in sensitiveness, but the gills were always the most sensitive region. The reactions of the gills to one per cent potassium hydroxide were greater than to ten per cent nitric acid, but the other regions of the body were less sensitive to potassium hydroxide or ammonium hydrate. The limit of reaction for both was a 0.01 per cent solution.

It is apparent from inspecting tables XVI-XIX that Necturus is more sensitive to magnesium sulphate than to magnesium chloride. The nostril region was the most sensitive to magnesium sulphate. At 0.05 per cent magnesium chloride the nostril region only was sensitive, while at the same per cent Necturus was sensitive to magnesium sulphate in the regions of the nostrils, head and gills. Necturus will not react to either chemical at 0.01 per cent.

TABLE XII

REACTIONS TO 1% POTASSIUM HYDROXIDE

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	Switch body F 14	B F 7	Switch body F 22	Switch body F 12	Switch body F 14	Switch body F 14	Switch tail
II	F 12	B F 7	Switch body F 22	F 7	F 9	F 9	Switch tail
III	B F 14	B F 12	Switch body F 22	Switch body F 12	F 9	F 12	F 12
IV	F 13	B F 8	Switch body F 14	Switch body F 10	F 8	F 7	Switch tail
Average	13.5	8.5	20	10.2	10	10.5	3

TABLE XIII

REACTIONS TO 0.05% POTASSIUM HYDROXIDE

Individual No.	Nostrils	Head	Gills
I	B 2 F 4	F 1	F 4
II	F 12	Moved in place	F 2
III	F 10	Head moved	Head moved
IV	F 6	F 5	F 7
Average	8.5	1.5	3.2

TABLE XIV

REACTIONS TO 1% AMMONIUM HYDRATE

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	X	B 6 F 4	F 20	F 4	F 6	F 7	F 5
II	F 9	B 2	F 6	F 5	F 2	F 10	F 10
III	F 12	B F 10	F 8	F 12	F 7	F 5	F 5
IV	F 10	X	F 12	F 12	F 7	F 8	F 10
Average	7.7	5.5	16.5	8.2	5.5	7.5	7.5

TABLE XV

REACTIONS TO 0.075% AMMONIUM HYDRATE

Individual No.	Nostrils	Head	Gills
I	B 2	X	F 2
II	B 2	F 2	F 1
III	0	0	0
IV	B 2 F 8	B 3	X
Average	3.5	1.2	.75

TABLE XVI

REACTIONS TO 2% MAGNESIUM CHLORIDE

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	F 14	F 10	F 22	F 8	F 8	F 6	F 7
II	F 9	F 14	F 10	F 10	F 5	F 5	0
III	B 2 F 6	F 12	F 18	F 8	F 3	F 7	F 10
IV	F 5	B 5	0	B 5	F 2	F 4	F 8
Average	9	10.2	12.5	7.7	4.5	5.5	6.2

TABLE XVII

REACTIONS TO 0.05% MAGNESIUM CHLORIDE

Individual No.	Nostrils
I	F 2
II	B 3
III	Moved head
IV	F 2
Average	1.7

TABLE XVIII

REACTIONS TO 2% MAGNESIUM SULPHATE

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	F 22	F 7	F 6	F 5	X	F 4	F 3
II	B F 26	F 8	F 10	F 10	F 10	F 6	F 6
III	F 10	F 12	F 22	X	F 9	F 4	F 5
IV	B F 14	F 20	F 12	F 18	F 6	F 7	X
Average	18	11.7	12.5	8.2	6.2	5.2	3.5

TABLE XIX

REACTIONS TO 0.05% MAGNESIUM SULPHATE

Individual No.	Nostrils	Head	Gills
I	B 1 F 2	F 2	F 2
II	B 2 F 2	B 1 F 2	F 3
III	Moved head	Moved head	Moved head
IV	B 1	B 1 F 2	F 1
Average	2	2	1.5

(c) *Reactions to Alcohol*

A study was made of the reactions of Necturus to alcohol at fifty per cent and ten per cent. Tables XX and XXI show these reactions. There was no reaction with one per cent. When nostrils were stimulated with either of the effective solutions there was a greater response than with any other region of the body. The gills and head were less sensitive. All regions responded when stimulated with a ten per cent solution and all regions except the pelvic and back were sensitive to ten per cent. Necturus is less sensitive to alcohol than to any other chemical used, as indicated by the stronger solution necessary to induce reaction.

TABLE XX

REACTIONS TO 50% ALCOHOL

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	B 4 F 18	F 14	B 2 F 12	F 4	F 2	F 10	F 3
II	B 6	F 9	B 4 F 12	F 10	F 3	F 8	Tail curled
III	B 3 F 20	F 12	B 3 F 12	F 18	F 7	F 8	F 2
IV	B 1 F 10	F 12	F 12	F 10	F 5	F 7	F 7
Average	15.5	11.7	14.2	10.5	4.2	8.2	3

TABLE XXI

REACTIONS TO 10% ALCOHOL

Individual No.	Nostrils	Head	Gills	Pectoral Girdle	Tail
I	F 4	F 3	F 4	F 2	F 3
II	B F 10	F 8	F 7	F 5	F 4
III	0	0	0	0	0
IV	F 12	F 8	F 10	F 4	F 7
Average	6.5	4.7	5.2	2.7	3.5

(*d*) *Reactions to Clove Oil and Turpentine*

Drops of clove oil were ejected upon the skin of Necturus with no results, except a slight response in the region of the nostrils. When Necturus, however, raised its body out of the water and thus carried some of the oil upon its skin, every portion was sensitive.

Cotton was saturated with turpentine and applied to Necturus with no result, whether the animal was in or out of water.

(*e*) *Summary of the Chemical Reactions*

1. Necturus is more sensitive to nitric than to hydrochloric or sulphuric acid. It is least sensitive to acetic. Responsiveness, is therefore, roughly proportional to degree of electrolitic dissociation.
2. Necturus is more sensitive to potassium sulphate than to potassium chloride.
3. Necturus is less sensitive to alcohol than to the acids, alkalies, or alkaline earth salts, as indicated by the high per cent of alcohol necessary to induce reactions.
4. The skin of Necturus is sensitive to clove oil in the air but not when under water. Whether in or out of the water, Necturus does not react to turpentine.

THE REACTIONS TO HEAT

Several experiments were performed with three individuals to determine the thermic reactions of Necturus.

When taken from the tank where the water was 10° C. and put into water at 30° C. the three animals made the most violent struggles, beginning almost immediately and lasting until they were completely exhausted. The violence of these struggles was quite remarkable, though less pronounced in some cases than in others. A very short stay in the warm water was sufficient to completely exhaust all the individuals, so that they turned ventral side up; but when returned to water of moderate temperature they soon recovered.

Removal from water at 10° C. to 25° C. induced locomotion also. The gills were spread out and moved rapidly. The nostrils were often lifted above the water and air was expelled.

At 18° C. and 15° C. the animals remained quiet, but the gills were moved rapidly. Reese ('06) in a similar experiment found two of the five Necturus under experiment gave locomotor responses at 18° C.

When put into water at 4° from 30°, the animals showed the same responses as noted by Reese ('06)—that is, marked activity, walking rapidly up and down the tank.

The reactions of certain regions of the body of Necturus to hot water was tested. A pipette that ejected 5 C.C. of water at a time was used and tests were made in water at 10° C. When the gills were stimulated with water at 70° C. the animal walked forward thirty inches, switching the body from side to side. The head, nostrils and tail were somewhat less sensitive. Their stimulation with water at 70° C. resulted in a forward movement of from eight to twelve inches. Water of the same temperature ejected on the back, caused only two or three inches of movement. The same regions of the body were tested in a like manner with 30° C., with no response.

Local heat stimulation was tested in another manner. A long rubber tube was run through the tank of water containing the animals. At one end of the tube was a funnel; the other end was open and hung outside of the tank. This arrangement allowed water to be poured in at the funnel, run through the tube and empty outside of the tank. To secure local response to heat, the tube was placed in contact with that region of Necturus to be stimulated. The tank water during this test was 0° C. and the water poured through the tube was 96° C. The tube was placed in contact with the body and the water was poured in at the funnel. When the nostrils, head and gills were stimulated the animal drew away from the tube immediately. This showed that direct response resulted from the heat radiating from the tube containing the heated water. Scarcely any response was induced from any other region of the body.

Another experiment was performed in which one end of a large pan, three by one and one-half feet, containing water was placed over a lighted gas burner and the other end on a cake of ice. The temperature of the heated end was 40° C., the cold end was 3° C., and the middle 10° C. Three animals were placed in the pan. They walked up and down several times, and finally rested in the cold end. When in the hot end they splashed and struggled, but several times remained in the heated portion and tried to get out of the pan. In many cases they stayed in the hot end for some time and burned themselves over and over again, before finally reaching the middle or cold end of the pan.

From the experiments described above it is evident that Necturus is sensitive to considerable changes in temperature. It is apparent that Necturus could not live successfully in water above 18° C. and that life in water at 30° C. would probably be impossible.

THE REACTIONS TO LIGHT

The experiments performed to determine the sensitiveness of the skin of Necturus to light were carried on in a dark room, the temperature of which ranged from 75°-70° F. A 144 candle-meter Nernst lamp was used in all the experiments.

The first experiment tested the reactions of Necturus to light and shadow, the lamp being at the side one foot from the tank and a movable screen interposed in such a way that one-half of the tank was in shadow and the other half in light. Three animals were successively introduced. At 23.4 candle-meters, all three immediately went to the dark end of the tank. When the screen was changed to the opposite half of the tank the animals again moved into the shaded area. At 5.7 candle-meters each animal moved about for some time, equally in the light and dark areas of the tank. At 2.5 candle-meters the response was slow. After three minutes all three animals moved their heads and about one-half of their bodies into the shaded area. When the screen was changed to the opposite half of the tank the animals did not attempt to move again into the shaded area but remained in the light. With the intensity at 1 candle-meter the response was very slow. After five minutes all three moved their heads into the dark and remained in that position.

Definite reactions in determining the relative sensitiveness of the body region of Necturus were brought about by illuminating small areas of the skin. The apparatus was in the same position as for the experiments first described, except that the screen was arranged in such a manner that a band of light (144 candle-meters above the water at the center of the tank) could be suddenly thrown on different regions of the body through a hole in the screen, three-eighths of an inch in diameter. Three individuals were used for this experiment and all of them behaved in essentially the same manner.

After an animal had remained quiet in the dark for five minutes it was suddenly illuminated and a following behavior noted. The reactions observed agree with those of Pearse ('10, p. 169) who performed similar experiments with Necturus. When the light fell on the tail the animal moved forward, but when it was allowed to fall on the head the movement was usually backward. The various regions of the body exhibit great variation in the time between stimulation and response. The reaction times of the regions subjected to the ray of light are shown in table XXII.

TABLE XXII

THE REACTION TIMES IN SECONDS OF VARIOUS REGIONS OF THE BODY TO LIGHT, 144 C. M.

Individual No.	Head	Pectoral Girdle	Back	Pelvic Girdle	Tail
I	19	90	162	159	153
II	22	130	203	180	120
III	15	180	240	120	120
Average	18.6	133.3	201.6	153	131

As Pearse ('10, p. 170) found the head most sensitive in normal Necturus while the tail was most sensitive in individuals with eyes removed, the greater sensitiveness of the head is due undoubtedly to stimulation received through the eye.

When the eye only was stimulated by a ray of light (144 C. M.) through a hole in the screen one-eighth of an inch in diameter, each animal moved away from the light in about thirty seconds, thus indicating the greater sensitiveness of the eye over any other region of the body.

As Pearse ('10) says: "It is evident that Necturus is negatively phototropic and that it comes to rest in shaded areas. Both the eyes and skin are photoreceptors, and the stimulation of either brings about negative reaction."

DISCUSSION

Let us try to picture Necturus in its daily life on the bottom of a lake or slow flowing stream. It frequents quiet waters from four to eight feet deep where a clean, sandy bottom is fairly well covered by vegetation. During the day it rests quietly beneath boards, logs or stones. One is rarely fortunate enough to get a glimpse of it; it is extremely shy and disappears at the slightest disturbance of the water, such as that caused by the approach of a boat. In walking, the diagonally opposite legs move in unison. When disturbed it swims swiftly, with a vigorous lateral motion of the broad and powerful tail, the feet being held closely against the body. Necturus never swims long distances, at most a few yards, then seeks concealment either in the mud or beneath some object. If it is undisturbed it usually rests with its head protruding from beneath a rock. The animal thus presents a curious appearance with its ruby gills moving gracefully to and fro. When one is disturbed the gills change from bright red to a dusky color and are at once drawn down tightly against the neck.

During the night Necturus moves from place to place. If it wanders into a warm area it becomes restless and walks away quickly into cooler water. It may approach dead vegetation that is giving off acids and alcohol. Such an environment drives Necturus away immediately. If it swims into an area containing an excess of salts or alkalies it quickly withdraws. Thus Necturus moves about, being directed hither or thither by the various changes in the chemical constitution or temperature of the water, till it comes into cool, pure water. Here it seeks crustaceans, insect larvae, small fish and earthworms, which constitute its food.

From the consideration of the facts of behavior one is naturally led to ask what the artificial conditions are which best suit the needs and instincts of Necturus. In aquaria it avoids the sunlight, and always seeks concealment. A tank well supplied with dark sheltered nooks is therefore best. Necturus can not live in warm water, and hence an aquarium should be supplied with running water and kept cool. Everything should be kept free from fungus, for a Necturus infected with Saprolegnia will not live long.

When Necturi are kept in aquaria they are frequently observed to thrust their snouts above the water, open the mouth wide, and then return to the bottom where they soon expel the air, both through the gill-slits and from the mouth. It would thus seem that, while the branchiae are the chief means of respiration, the lungs play considerable part.

The great tenacity of life showed by mud-puppies is a matter of frequent comment. They are able to live for months without food and may be easily revived after being left for three or four hours out of water. After severe mutilation they recover and regenerate lost parts. Notwithstanding this great vitality they seem to fall easy victims to Saprolegnia, especially if there is a slight abrasion on the skin.

SUMMARY

1. The skin of Necturus is everywhere sensitive to tactile stimulation. The regions about the nostrils, gills and tail are most sensitive and the back the least sensitive.

2. Necturus is sensitive to chemical stimuli over the entire body surface, the reactions being characteristic for the different regions stimulated. The gills are usually the most sensitive region, with the nostrils and head following in order.

3. Necturus is more sensitive to nitric than to hydrochloric or sulphuric acid. It is least sensitive to acetic acid. It is more sensitive to potassium sulphate than to potassium chloride.

4. When any region of the body is fatigued for a given chemical, it rarely responds to tactile stimuli, although it usually reacts to other kinds of chemical stimuli.

5. Necturus is sensitive to considerable changes in temperature. All parts of the body are sensitive to hot water (70° C.), but the gills, head and nostrils are the most sensitive regions.

6. Necturus is negatively phototropic and comes to rest in shaded areas. Both the eyes and skin are photoreceptors and the stimulation of either brings about negative reactions. The head and tail are the most sensitive regions.

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EXPERIMENTS ON THE BEHAVIOR OF CHICKS HATCHED FROM ALCOHOLIZED EGGS

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During 1912, in the Biological Laboratory of H. Sophie Newcomb College of Tulane University, experiments were carried on relative to the effect of subjecting chicken eggs to alcoholization before hatching. It was discovered possible to hatch from eggs so treated chicks which were apparently of normal physical structure. When a technique had been evolved which attained this end the experiment was taken up and carried on by the Department of Psychology in an attempt to discover whether there was any characteristic modification of behavior which could be attributed to the effect of the alcohol on chicks hatched from alcoholized eggs.

The experiments extended from October, 1913, to June, 1914, and from March, 1915, to May, 1915. In the course of the work five sets of eggs were hatched. The first, fourth and fifth hatchings were from mixed stock; the second was in part pure bred Buff Orpington and part pure bred White Leghorn and the third was of Rhode Island Red stock. The eggs numbered seventy in each hatching except the third, when only sixty eggs were used. Of each of the first four sets of eggs twenty-five were not tampered with. The remainder of the eggs, just before being placed in the electric incubator, were treated in the following manner: A hole was made in the air chamber of the egg with a dissecting needle. Into the air chamber was injected, by means of a hypodermic needle, five drops of 95% ethyl alcohol. In some cases the air chamber was found to be too small to hold five drops so some eggs had less than five drops. None had more. After the alcohol was in, the hole was sealed with hot sealing wax. Of the last hatching of eggs ten were left untampered with, ten were merely pierced with the dissecting needle and sealed, twenty-five were injected with five drops of distilled water in place of the alcohol, and twenty-five were injected with alcohol as usual. The incubator was always divided into compartments which prevented the chicks from the different groups of eggs from mixing as they hatched. As the chicks were taken from the incubator they were marked with pigeon markers having numbers on them and from that time on were kept together and treated in exactly the same way except in the case of a few which were isolated as a check on the imitation factor. For purposes of convenience the chicks which were hatched from normal eggs will be designated "normal;" those hatched from alcoholized eggs will be designated "alcohol;" those hatched from eggs with distilled water in them will be designated "water;" and those hatched from eggs with holes in them will be designated "holes."

In observing the behavior of the chicks their reactions were divided into two groups, inherited and acquired. The inherited reactions studied were, reactions to light, pecking and drinking reactions, and reactions to height. The acquired reactions were those involved in choice between two visual stimuli presented by means of the Yerkes apparatus, as modified by Breed,[1] and those involved in learning to run mazes. Promptness and direction of response to light, speed and accuracy of the pecking and drinking reactions, and the height from which a chick would jump were used as criteria of the types of behavior of the first group. The number of trials necessary before making ten correct choices and the time spent in the mazes were criteria of the second group of reactions.

The instinctive reactions of alcohol chicks differed little, if at all, from those of normal chicks except in the case of reactions to height. After the fifteenth day the alcohol chicks jumped from greater heights than did the normal. Alcohol chicks were, as a group, slower in reacting within the mazes and had to be given more trials before they made ten correct choices in the Yerkes apparatus. The water chicks and the hole chicks were tested only for pecking reactions and mazes. Their behavior resembled much more nearly that of the alcohol chicks than that of the normal chicks. The different reactions will be taken up in detail in the following pages.

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[1] Breed, F. S. The Development of Certain Instincts and Habits in Chicks. *Behav. Monog.*, vol. 1, no. 1, 1911.

We are happy to have this opportunity to express our lasting gratitude to President B. V. B. Dixon for hearty co-operation in the experiment and to Dr. Irving Hardesty and Dr. Gustav Mann, of the Medical College of Tulane University, to whose suggestions for technique we owe much. Our greatest debt is to Miss Ellinor H. Behre, of the Department of Biology, whose biological resourcefulness and unmeasured helpfulness in the carrying on of the work made it possible. To Professor J. A. Lyon, of the Department of Physics, we are indebted for the apparatus used in the experiments with reactions to light. To Professors Angell and Carr of Chicago University we are also indebted for valuable suggestions.

EXPERIMENTS WITH INHERITED REACTIONS

Reactions to Light

The apparatus used to test the first reactions to light of the first set of chicks consisted of a hooded light placed behind a cardboard screen in such a way that a single horizontal strip of light 5 mm. in width was visible between the screen and the table, affording a single, highly localized stimulus. The experimental table stood in a dark room used for photographic purposes. No light was permitted to enter the incubator from the nineteenth to the twenty-fourth day of the hatch.

On the twenty-fourth day the incubator was taken to the dark room. Fourteen chicks, seven normal and seven alcohol, (the extent of the hatch) were removed from the incubator one at a time, numbered and marked with cloth markers and placed one at a time on the experimental table eighteen inches from the stimulus. Of the seven normal chicks only one reacted definitely. This chick walked towards the light, stopped, went on towards the light, stopped, then went straight to the light streak and tried to nestle in a corner of the screen. Four of the seven normal chicks walked away from the screen. Of the seven alcohol chicks, five went to sleep after making a few random movements, one stood still screaming and one ran about the table, finally running off and up the experimenter's arm. Light was thrown on the heads of the first two chicks which were tested but elicited no response.

After this test this apparatus was discarded because so much light from the stimulus was reflected on the walls of the room. The following apparatus was found eminently satisfactory and was used throughout the rest of the series of experiments with light. It consisted of a one-candle power incandescent light connected in series with a rheostat and so arranged that by varying the resistance of the circuit the light could be adjusted from zero to full intensity. The stimulus was found to give best results when adjusted to about one-half full intensity. The apparatus was on a table covered by a cloth of dull black material having a minimum refractive power. The experiments were conducted at night.

At the time of the second hatch all light was excluded from the incubator from the nineteenth to the twenty-fourth day. On the evening of the twenty-fourth day ten chicks, five normal and five alcohol, were removed from the incubator one at a time, numbered and marked with aluminum pigeon markers and placed on the table, eighteen inches from the stimulus. They were so placed that their heads were turned slightly away from the light. Three alcohol and two normal chicks reacted positively. Turning and facing the stimulus, they walked toward it. The other chicks walked diagonally or directly away from the light. Two normal and one alcohol chick walked off the table.

On the following night the same procedure was repeated with the ten chicks previously tested and eleven others, four normal and seven alcohol, which had been too weak to be handled on the first night. Of the ten previously tested, eight reacted positively. No. 36, which had reacted slowly and Nos. 4, 6 and 35, which had not reacted at all, walked directly to the light as soon as placed on the table. Of the four normal chicks not tested before one reacted positively to the stimulus, walking directly to the light and placing its bill against it; the other three walked away from the light. Of the alcohol chicks not tested before three immediately moved toward the light, one after an interval of three minutes, and the other three walked around the table, going sometimes towards, sometimes away from the light.

The twenty-one chicks were tested again on the third day. Normal chick No. 3 and alcohol No. 34, which had reacted positively on the first and second days, did not react on the third; normal No. 4 reacted on the second, but not the first and third days; alcohols No. 21 and No. 33 reacted on the third, but not on the second day; normal chicks Nos. 2, 6 and 10, and alcohol chicks Nos. 36, 22, 27 and 35 reacted positively through the third day; normal chicks Nos. 11, 8, 7 and 1, and alcohol chicks Nos. 27, 26, 31, 28 and 24 did not react positively at any time.

The apparatus and procedure employed with the third hatching of chicks was the same as that used with the second hatching but these chicks were not removed from the incubator until the evening of the third day. At the end of the first day a partition was placed in the incubator in such a manner that the chickens hatching later would not mingle with those already hatched. Only those which had hatched the first day were tested. Of the six alcohol and eleven normal chicks tested, two alcohol chicks reacted positively, the other fifteen chicks did not react at all, wandering aimlessly about the table or standing still and screaming.

There is nothing in these results or in the behavior of the chicks, as they moved toward or away from the light stimulus, to indicate the presence of a phototropism either positive or negative. There seems to be a highly variable instinctive tendency to react positively to a single light stimulus of very weak intensity and small area. This tendency may appear for the first time on the first or second day and rarely on the third day. When it does appear before the third day it may not persist through that day. This reaction failed to show any characteristic difference between normal and alcohol chicks.

Pecking Reaction

The pecking reactions of the first set of chicks are not recorded here as the cloth markers which distinguished normal from alcohol chicks dropped off the evening of the fourth day. These chicks were not used for further experiments.

The following method was used with the second set of chicks. On the morning of the third day after hatching the chicks were placed, one at a time, on a table covered with a smooth, black cloth. On this cloth were scattered several bits of light colored grain. The time before the first peck and the accuracy of the pecking reaction was carefully noted. For the first test with each chick a record was kept during the first five minutes of its pecking activities. For succeeding tests the record was kept for three minutes. It was found convenient to use the Breed method of recording reactions, i.e., to use "1" to denote pecking at but missing grain; "2", pecking at and hitting grain; "3", pecking, hitting, picking up and dropping grain; "4", pecking at, striking, picking up and swallowing grain, or the complete reaction.

On the occasion of the first test the alcohol chicks with the exception of Nos. 22 and 29, pecked after longer intervals than did the normal chicks. Alcohols Nos. 28 and 21 did not peck at all. Alcohols Nos. 33, 39 and 34 went to sleep a number of times before they pecked at the grain. All of the alcohol chicks were quieter than the normal, made fewer random movements and showed little or none of the tendency to explore, so apparent in all of the normal chicks. They did, however, peck with accuracy equal to that of the normal chicks and their records show they improved with equal rapidity.

Alcohols Nos. 33 and 34 made only 24% and 20% of "4" reactions respectively on the third day. On the eleventh day No. 34 made 51.1% and No. 33 made 44.4% of "4" reactions. One of the normal chicks, No. 10, made a better record than any made by alcohol chicks, making 78.9% of "4" reactions on the eleventh day; but the records of Nos. 8, 6 and 1 were not so good as those made by some of the alcohol chicks. No. 7 had 35.2%, No. 6, 44.4% and No. 1, 47% of "4" reactions on the eleventh day. The following table shows the comparative rate of progress of normal and alcoholic chicks of the second group.

TABLE 1

Chicks 1, 2, 6 and 10 Were Normal Chicks. Chicks 21, 22, 29, 32, 34 and 35 Were Alcohol Chicks

	Day 3 Reaction				Day 4 Reaction			
No. of Chick	1	2	3	4	1	2	3	4
1					1	2	4	2
2								
6	0	8	5	2				
10					0	3	3	2
Average	0	8	5	2	1/2	2 1/2	3 1/2	2
21								
22	1	2	5	3				
29	4	9	7	5				
32	8	7	6	4	2	3	5	5
34	0	5	5	2				
35	0	1	9	3				
Average	2 3/5	4 4/5	6 2/5	3 2/5	2	3	5	5

TABLE 1—*Continued*

No. of Chick	Day 5 Reaction 1	2	3	4	Day 8 Reaction 1	2	3	4
1.					1	1	13	1
2.	0	4	4	11	0	1	13	11
6.	0	5	5	4	0	1	1	1
10.					0	3	4	12
Average.	0	4 1/2	4 1/2	7 1/2	1/4	1 1/2	7 3/4	6 1/4
21.	1	1	1	0	0	3	7	5
22.	5	3	2	2	0	0	11	12
29.	4	5	4	4	0	0	7	14
32.	2	5	7	6	8	2	10	6
34.	4	3	9	3	0	0	11	3
35.					0	4	6	5
Average.	3 1/5	3 2/5	4 3/5	3	1 1/3	1 1/2	8 2/3	7 1/2

No. of Chick	Day 10 Reaction 1	2	3	4	Day 11 Reaction 1	2	3	4
1.	0	1	11	8	0	1	8	8
2.	0	0	5	18	0	0	5	11
6.	0	3	4	12	0	4	6	8
10.	0	0	6	21	0	0	4	15
Average.	0	1	6 1/2	14 3/4	0	1 1/4	5 3/4	10 1/2
21.	0	0	11	15	0	1	9	6
22.	0	1	8	8	0	0	1	4
29.	0	0	3	19	0	2	8	5
32.	1	1	10	8	0	4	6	6
34.	0	1	8	8	0	1	8	10
35.	0	5	4	5	0	1	12	3
Average.	1/6	1 1/3	7 1/3	10 1/2	0	1 1/2	7 1/2	5 2/3

TIME UNTIL FIRST

No. of Chick	Time Until First Peck	No. of Chick	Time Until First Peck
1	1′ 20″	21	
2	1′ 30″	22	15″
6	2′ 10″	29	30″
10	30″	32	2′ 29 1/2″
		34	5′
		35	9′ 50″
Average	1′ 22 1/2″	Average	3′ 36.9″

The same apparatus and procedure was repeated with the third set of chicks with approximately the same results. The highest record in this group as in the second was made by a normal chick, the lowest by an alcohol, but the records of the other chicks differed little if at all. The following table (Table

2) presents the rate of improvement of the pecking reaction of normal and alcohol chicks.

TABLE 2

Chicks 2, 3, 5, 6, 8, 15 and 16 Were Normal Chicks. Chicks 21, 22, 24, 29, 31, 33 and 34 Were Alcohol Chicks

No. of Chick	Day 3 Reaction 1	2	3	4	Day 4 Reaction 1	2	3	4
2	12	3	6	5				
3	10	0	5	6	3	5	7	6
5	0	2	8	13				
6					0	9	7	5
8								
15								
16	5	9	6	5				
Average	6 3/4	3 1/2	6 1/4	7 1/4	1 1/2	7	7	5 1/2
21	7	6	9	1				
22								
24					0	7	4	9
29					9	6	2	2
31	0	13	6	3				
33								
34					0	5	2	16
Average	3 1/2	9 1/2	7 1/2	2	3	6	2 2/3	9

No. of Chick	Day 5 Reaction 1	2	3	4	Day 6 Reaction 1	2	3	4
2	0	3	1	2	0	0	2	18
3	0	5	5	14	0	3	3	16
5	0	3	3	14	0	3	8	22
6					0	6	6	19
8	3	7	4	7	0	6	8	22
15	3	0	0	0	0	3	8	25
16	12	5	2	5	0	5	5	15
Average	3	3 5/6	2 1/2	7	0	4 1/3	6 2/3	22 5/6
21	0	9	4	17				
22	0	4	5	12				
24					0	19	3	19
29	7	9	4	2	0	13	4	3
31	0	4	4	13				
33	1	11	3	13	0	0	5	16
34	0	5	2	16	0	0	5	15
Average	1 1/3	7	3 2/3	12 1/6	0	8	4 1/4	13 1/4

TABLE 2—*Continued*

No. of Chick	Day 8 Reaction 1	2	3	4	Day 10 Reaction 1	2	3	4
2	0	4	4	14	0	1	5	13
3	0	6	7	7	1	2	8	11
5	0	1	5	14	0	1	7	12
6	0	5	9	6	0	3	7	15
8	0	4	5	16	0	1	6	14
15	0	2	7	11	0	7	3	12
16	0	3	4	15	0	1	7	15
Average	0	3 4/7	5 6/7	11 6/7	1/7	2 2/7	6 1/7	13 1/7
21	0	3	6	14	0	2	5	15
22					0	3	4	17
24	0	14	4	14	0	14	3	14
29	0	6	6	9	0	0	2	5
31	1	2	4	18	0	7	4	14
33	0	5	4	16	0	4	3	16
34	0	6	6	17	1	4	7	9
Average	1/6	6	5	14 2/3	1/7	4 6/7	4	12 6/7

No. of Chick	Day 11 Reaction 1	2	3	4	Time Until First Peck
2	0	3	3	14	17′ 4″
3	0	7	1	20	2′ 10″
5	0	4	4	14	4″
6	0	2	5	18	38′ 4″
8	0	4	2	19	51.6″
15	0	5	3	20	1′ 28″
16	0	7	4	14	
Average	0	4 4/7	3 1/7	17	9′ 56.9″
21	0	1	4	20	3′ 34″
22	0	3	3	19	4″
24	0	13	5	13	15″
29	0	3	3	14	4′
31	0	5	4	16	2′ 20″
33	0	3	2	19	4′
34	0	2	3	19	8″
Average	0	4 2/7	3 3/7	17 1/7	1′ 52″

The fifth hatching of chicks, which consisted of seven normal, four hole, seven water and five alcohol chicks, were also tested for pecking reactions. The method differed slightly from that of the preceding tests in that a record was kept of the first twenty reactions in each test rather than of the total reactions for a certain length of time. No record was made of the time which elapsed before the first pecking reaction in the first test. In all other respects the method for this group was like that for the preceding groups.

The following table shows the rate of improvement in pecking accuracy of each chick tested:

TABLE 3

Chicks 1, 2, 3, 4, 6, 10 and 14 Were Normal Chicks. Chicks 20, 21, 23 and 25 Were Hole Chicks. Chicks 41, 43, 46, 47, 48, 51 and 54 Were Water Chicks. Chicks 71, 72, 74, 80 and 81 Were Alcohol Chicks

	Day 2 Reaction				Day 3 Reaction			
No. of Chick	1	2	3	4	1	2	3	4
1	0	14	1	5				
2	6	6	0	8				
3	0	10	3	7				
4	2	6	1	11	0	4	2	14
6	1	9	4	6				
10	0	4	1	15				
14					0	8	1	11
Average	1 1/2	8 1/6	1 2/3	8 2/3	0	6	1 1/2	12 1/2
20					0	13	1	6
21	4	4	2	10				
23	0	7	6	7				
25	1	8	1	10	0	8	6	6
Average	1 2/3	6 1/3	3	9	0	10 1/2	3 1/2	6
41	0	6	3	11				
43	0	12	4	4				
46	9	3	4	4				
47					0	7	8	5
48					0	8	1	11
51	1	4	5	10				
54	7	5	5	3				
Average	3 2/5	6	4 1/5	6 2/5	0	7 1/2	4 1/2	8
71	3	10	4	3				
72	1	6	0	13				
74								
80					0	9	3	8
81	7	5	2	6	1	2	1	16
Average	3 2/3	7	2	7 1/3	1/2	5 1/2	2	12

TABLE 3—*Continued*

No. of Chick	Day 5 Reaction 1	2	3	4	Day 6 Reaction 1	2	3	4
3.					0	1	10	9
6.					2	1	10	7
10.					0	3	15	2
Average.					2/3	1 2/3	11 2/3	6
21.					0	1	11	8
23.					0	1	17	2
Average.					0	1	14	5
43.					0	5	7	8
46.					0	0	19	1
Average.					0	2 1/2	13	4 1/2
71.					0	4	9	7
72.	0	5	8	7	0	0	5	15
74.					0	2	10	8
Average.	0	5	8	7	0	2	8	10

No. of Chick	Day 7 Reaction 1	2	3	4	Day 10 Reaction 1	2	3	4
2.	0	0	3	17				
3.					0	4	7	9
4.	0	0	7	13				
6.					0	1	8	11
10.					0	1	13	6
14.	0	2	5	13				
Average.	0	2/3	5	14 1/3	0	2	9 1/3	8 2/3
20.	0	0	1	19				
21.					0	3	4	13
25.					0	0	4	16
Average.	0	0	1	19	0	1 1/2	4	14 1/2
41.	0	1	10	9				
43.					0	4	13	3
46.					0	0	6	14
47.	0	1	13	6				
48.	1	4	9	5				
51.					1	3	6	10
Average.	2/3	2	10 2/3	6 2/3	1/3	2 1/3	8 1/3	9
71.					0	2	7	11
72.					0	0	3	17
74.					0	4	7	9
81.	0	0	7	13				
Average.	0	0	7	13	0	2	5 2/3	12 1/3

TABLE 3—*Continued*

No. of Chick	Day 13 Reaction			
	1	2	3	4
2	0	0	1	19
4	0	1	5	14
14	0	3	7	10
Average	0	1 1/3	4 1/3	14 1/3
20	0	2	3	15
Average	0	2	3	15
41	0	1	9	10
47	0	4	7	9
48	0	9	8	3
Average	0	4 2/3	8	7 1/3
80	0	0	13	7
81	0	1	7	12
Average	0	1/2	10	9 1/2

No. of Chick	Day 14 Reaction				Day 16 Reaction			
	1	2	3	4	1	2	3	4
3	0	0	4	16				
6	0	1	3	16				
10	0	0	6	14				
Average	0	1/3	4 1/3	15 1/3				
21	0	0	1	19				
23	0	1	13	6				
25	0	0	2	18				
Average	0	1/3	5 1/3	14 1/3				
43	0	0	3	17				
46	0	1	3	16				
48					0	4	7	9
51	0	2	4	14				
Average	0	1	3 1/3	15 2/3	0	4	7	9
71	0	1	8	11				
72	0	0	1	19				
74	0	0	1	19				
Average	0	1/3	3 1/3	16 1/3				

TABLE 3—*Continued*

No. of Chick	Day 17 Reaction 1	2	3	4	Day 19 Reaction 1	2	3	4
2	0	1	9	10				
3					0	2	15	3
4	0	1	9	10				
6					0	2	10	8
10					0	2	9	9
14	0	1	2	17				
Average	0	1	6 2/3	12 1/3	0	2	11 1/3	6 2/3
20	0	2	7	11				
21					0	1	8	11
23					0	2	7	11
25					0	2	6	12
Average	0	2	7	11	0	1 2/3	7	11 1/3
41	0	0	7	13				
43					0	3	13	4
46					0	2	9	9
47	0	5	6	9				
51					0	2	8	10
Average	0	2 1/2	6 1/2	11	0	2 1/3	10	7 2/3
72					0	0	3	17
74					0	1	7	12
80	0	3	14	3				
81	0	0	11	9				
Average	0	1 1/2	12 1/2	6	0	1/2	5	14 1/2

No. of Chick	Day 20 Reaction 1	2	3	4	Day 21 Reaction 1	2	3	4
2	0	1	4	15				
3					0	3	10	7
4	0	1	3	16				
6					0	1	9	10
10					0	2	6	16
14	0	1	4	15				
Average	0	1	3 2/3	15 1/3	0	2	8 1/3	11
20	0	2	4	14				
21					0	0	5	15
23					0	2	8	10
25					0	2	5	13
Average	0	2	4	14	0	1 1/3	6	12 2/3

TABLE 3—*Continued*

No. of Chick	Day 20 Reaction				Day 21 Reaction			
	1	2	3		1	2	3	4
41	0	1	2	17				
43					0	1	13	6
46					0	3	6	11
47	0	6	6	8				
48	0	4	6	10				
51					1	2	5	12
Average	0	3 2/3	4 2/3	11 2/3	1/3	2	8	9 2/3
71					0	1	4	15
72					0	0	2	18
74					0	3	2	15
80	0	6	3	11				
81	0	1	4	15				
Average	0	3 1/2	3 1/2	13	0	1 1/3	2 2/3	16

No. of Chick	Day 24 Reaction				Day 27 Reaction			
	1	2	3	4	1	2	3	4
2	0	3	5	12				
4	0	2	7	11				
6					0	1	6	13
10					0	2	8	10
14	0	1	8	11				
Average	0	2	6 2/3	11 1/3	0	1 1/2	7	11 1/2
20	0	0	1	19				
21					0	4	6	10
23					0	0	13	7
25					0	4	3	13
Average	0	0	1	19	0	2 2/3	7 1/3	10
41	0	2	2	16				
43					0	1	9	10
46					0	2	8	10
47	2	4	6	8				
48	2	3	9	6				
51					0	1	6	13
Average	1 1/3	3	5 2/3	10	0	1 1/3	7 2/3	11
71					0	1	14	5
72					0	5	3	12
74					0	1	7	12
80	0	5	9	6				
81	0	5	5	10				
Average	0	5	7	8	0	2 1/3	8	9 2/3

The Effect of Imitation on the Pecking Reaction

Some authors, notably Lloyd Morgan,[2] and Holmes[3], are of the opinion that imitation plays a large part in the perfecting of the pecking reaction. Holmes states that imitation is an important factor in the education of young birds. The following passage may be quoted from Lloyd Morgan: "A hen teaches her little ones to pick up grain and other food by pecking on the ground and dropping suitable materials before them, while they seemingly imitate her action in seizing the grain."

Thorndike,[4] is of the opinion that the pecking instinct is practically perfect at birth. Watson,[5] believes that the improvement in the speed and accuracy of the pecking reaction is due solely to practice. In support of his view he quotes the results of Breed's[6] experiments with five-day old chicks which had been prevented from previous pecking. These chicks pecked with the accuracy of twenty-four-hour old chicks and required two days' practise before their accuracy was up to standard.

In order to determine what rôle, if any, imitation played in the perfecting of the pecking reactions of our normal and alcohol chicks, three normal and three alcohol three-day old chicks of the second set were placed in separate pens. These pens were so constructed that each chick was kept completely isolated from and out of sight of the rest. The chicks were kept in these pens for eleven days and tested on the same days and by the same method as the group from which they were taken. Alcohols Nos. 21 and 28 were among the six chosen as they had not pecked at all when under observation on the third day.

Two chicks, alcohol No. 28 and normal No. 7, died when seven days old. The pecking reactions of the four remaining chicks improved as rapidly as those of the group from which they were taken. Alcohol No. 21 made a higher record than was made by any other alcohol chick in spite of the fact that it did not peck at all while under observation on the third day and did not see any other chick peck at that time or any time thereafter until replaced with the other chicks on the eleventh day.

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[2] Morgan, Lloyd. Animal Behavior., p. 189.

[3] Holmes, S. J. The Evolution of Animal Intelligence, p. 254.

[4] Thorndike, E. L. Animal Intelligence, 1911, p. 160.

[5] Watson, J. B. Behavior: An Introduction to Comparative Psychology, p. 141.

[6] Breed, F. S. Maturation and Use of an Instinct. *Jour. of Animal Behav.*, 1913, **3**, 274.

The following table gives the record of the pecking reactions of these chicks during their period of isolation:

TABLE 4

Chicks 4 and 8 Were Normal Chicks. Chicks 20 and 21 Were Alcohol Chicks

No. of Chick	Day 3 Reaction 1	2	3	4	Day 5 Reaction 1	2	3	4
4...........	4	2	1	1	0	7	4	7
8...........	3	2	2	2				
Average.......	3 1/2	2	1 1/2	1 1/2	0	7	4	7
20...........					0	5	6	7
21...........					2	3	9	13
Average.......					1	4	7 1/2	10

No. of Chick	Day 8 Reaction 1	2	3	4	Day 10 Reaction 1	2	3	4
4...........	0	4	6	10	0	5	9	2
8...........	0	2	12	11	0	5	7	7
Average.......	0	3	9	10 1/2	0	5	8	4 1/2
20...........	0	1	8	13	0	0	5	12
21...........	0	0	3	19	0	1	15	1
Average.......	0	1/2	5 1/2	16	0	1/2	10	6 1/2

No. of Chick	Day 11 Reaction 1	2	3	4
4...........	0	0	8	9
8...........	0	4	7	6
Average.......	0	2	7 1/2	7 1/2
20...........	0	0	7	10
21...........	0	0	8	10
Average.......	0	0	7 1/2	10

Drinking Reaction

A watch glass containing a few drops of water was used as a stimulus for the drinking reaction. This glass stood on a square of smooth, white paper, ten by ten inches. The chicks were placed one at a time on the paper, six inches from the glass, and a record made of the time before they drank and of their manner of doing it.

The drinking reactions of twenty chicks of the first set were observed, seven on the third and thirteen on the fourth day. Only one of the seven three-day old chicks drank and that one apparently found the way by accident, first walking into the glass and then drinking. Five of the thirteen four-day old chicks, three alcohol and two normal, walked to the glass and drank, one drinking at once, the others after a short interval. Three, one normal and two alcohol, afterwards performed the drinking reaction on the smooth, white paper and the edge of the glass. One chick pecked at the water, then swallowed and immediately performed the drinking reaction. The others were placed close to the glass after a long interval during which they had run about the table and the water was ruffled as in the Breed[7] experiment. The chicks then drank.

The same apparatus and method was used with the second set of chicks. The twenty-two chicks of this set found the water by accident, walking into the watch glass, or pecking at it and then drinking. One alcohol chick, No. 32, walked into the glass and immediately made the drinking reaction on the white paper on which the glass stood, walked out of the glass on to the paper, then walked back into the glass and went through the movements of the drinking reaction, scratching in the water at intervals. The touch of the water on the chick's feet had evidently served to start the drinking reflex. There was no difference in the behavior of alcohol and normal chicks of either set.

Reaction to Heights

Thorndike[8], experimenting with reaction to heights with chicks ninety-four hours old, found the chicks hesitated for a longer and longer interval before jumping, as the height of the boxes on which they were placed increased, finally refusing to jump from boxes thirty-nine inches in height.

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[7] Breed, F. S. The Development of Certain Instincts and Habits in Chicks. *Behav. Monog.*, vol. I, no. 1, 1911.

[8] Thorndike, E. L. Animal Intelligence, 1911, p. 159.

We undertook to determine the height at which our chicks would refuse to jump and whether this height differed for normal and alcohol chicks. The subjects were six seven-day old chicks, three normal and three alcohol, and seven fifteen-day old chicks, two normal and five alcohol.

The chicks were placed on stands above the box in which the other chicks were kept. The distance from the top of the stand to the floor of the box increased gradually from 10.7 cm. to 171.5 cm. The alcohol chicks were not placed on stands of greater height than 171.5 cm., as it was feared that they might be injured in jumping to the box. The chicks were allowed to rest and feed for thirty seconds after each return to the box.

There was little difference in the reactions of normal and alcohol six-day old chicks (see Table 5), but in the case of the fifteen-day old chicks the difference in behavior of the normal and alcohol chicks was marked. The normal chicks hesitated for longer and longer intervals as the height of the stands increased, waiting for over five minutes before jumping from a stand 106 cms. above the box. Though repeatedly pushed they would not jump from stands above this height. The alcohol chicks jumped with little or no hesitation. No. 32 would not jump from a stand 134 cm. in height, but Nos. 21, 28 and 22 jumped with almost no hesitation from stands 171.5 cm. above the box.

The following tables present in detail the results of the experiments with heights:

TABLE 5

Chicks 1, 2 and 10 Were Normal Chicks. Chicks 27, 35 and 34 Were Alcohol Chicks. The Fact That the Chick Jumped is Indicated by +. The Fact That the Chick Refused to Jump is Indicated by —.

Chicks Six Days Old

	Height									
No. of Chick	10.7	22.3	59.6	74	84.6	95	119.6	130	134	143
1	+	+	+	+	+	+	+	+	—	—
2	+	+	+	+	+	+	+	—		
10	+	+	+	+	+	—				
27	+	+	+	+	+	+	+	+	—	
35	+	+	+	+	+	+	+	+	—	
34	+	+	+	+	—					

TABLE 6

Chicks 4 and 8 Were Normal Chicks. Chicks 21, 22, 28, 29 and 32 Were Alcohol Chicks. The Fact That the Chick Jumped is Indicated by +. The Fact That the Chick Refused to Jump is Indicated by —.

Chicks Fifteen Days Old

	Height								
No. of Chick	10.7	22.3	74	89.8	95.5	106	134	158.3	171.5
4	+	+	+	+	+	—			
8	+	+	+	+	+	—			
21	+	+	+	+	+	+	+	+	+
22	+	+	+	+	+	+	+	+	+
28	+	+	+	+	+	+	+	+	+
29	+	+	+	+	+	+	+	+	+
32	+	+	+	+	+	+	—		

ACQUIRED REACTIONS

Experiments on Behavior in Mazes

During the course of the experiments with mazes three mazes of varying complexity were used which will be designated as Maze 1, Maze 2 and Maze 3. Maze 3 was used only with the fifth hatching of chicks, which contained hole and water chicks as well as normal and alcohol ones. The time which the animal spent in the maze was the criterion of learning.

So far as the general behavior of the chicks in the mazes was concerned there seemed to be one main difference which was, however, quantitative rather than qualitative. The alcohol chicks were on the whole less prone to react to the maze situation with general activity. An ordinary normal chick, when placed in a maze, will run about and attempt to get out. It will normally continue this running until it does get out and subsequent trials are made shorter by a gradual reduction of this running about. In other words, the process of learning the maze is like that of any other animal so placed. The alcohol chicks, as well as chicks raised from eggs which had been tampered with in other ways, that is, the three different kinds of abnormal chicks, did not seem to be inspired by this desire to get out of the maze. The situation did not seem to call forth the reaction of running about as it did with the normal chicks. The chick when placed in the maze might go promptly to sleep and sleep for some five minutes. It might then wake up and suddenly dart forward. If it brought up in a blind alley it might either go to sleep for another period, trying to the experimenter's nerves, or it might turn and go into the correct path and so out. This sort of procedure naturally made the time record of the abnormal chick much longer than that of the normal chick. But there are many modifying points which must be considered when discussing this difference in the learning process involved in learning mazes. In the first place this time difference was not one which persisted throughout the learning process. The results will show that it is confined mainly to the first third of the number of trials used. After this point the time records of the abnormal chicks do not vary from those of the normal. On this account we are very doubtful whether this can be called a genuine difference in the learning process of normal and abnormal chicks. Another consideration is the fact that this lack of reaction while prevalent among the abnormals was not invariable among them and was occasionally found among the normals. A glance at the tables will show that there were chicks among the alcohols, among the water and among the hole chicks whose records were as good or better than the average of the normal chicks. And there were individuals among the normals who showed the same lack of interest during the first trials in the maze that the abnormal chicks showed. And the final consideration is that the fact that a chick, either normal or abnormal, exhibited this sluggish type of behavior in a maze on one day did not necessarily mean that it would exhibit this same type of behavior in a different maze on another day. Again a glance at the individual records will confirm this.

The experiments with the mazes seemed to indicate, then, that tampering with an egg in the ways we used would cause the chicken subsequently developing from it to be subject to fits of sluggishness and inactivity which might temporarily impede its progress in acquiring a new co-ordination. They did not in any way demonstrate the inability of such a chick to acquire new co-ordinations, nor did they even demonstrate that this sluggishness is an inevitable result of the tampering, or a constant characteristic of the chick in which it appears or a characteristic which does not sometimes appear in normal chicks. The ordinary chicken raiser who remarks that a certain chicken "looks droopy and may be sick" is well acquainted with the type of behavior or lack of behavior we have been trying to describe.

The following pages present the maze results in detail:

Maze No. 1

Maze No. 1 (which perhaps should not properly be called a maze) was a straight path between two boards 55 cms. in length. It stood on a table below which was the box in which all the chicks were kept during the tests. One end of the path was closed. The open end was even with the edge of the table just above the box. During the tests of chicks 2, 6, 7, 9 and 34 the box was 79 cms. below the table edge. The wire netting cover of the box was made to lean against the table in such a way as to form an inclined plane from the table edge to the box. The chicks showed such reluctance to leave the table under these circumstances that the box was raised to within six inches of the table and the inclined plane done away with.

The chick to be tested was placed at the back of the maze and the time it took to find its way back to the box recorded. Each chick was given ten trials in succession. An interval of one minute was allowed to elapse between the end of one trial and the beginning of another. The chick was sometimes placed in the maze by one experimenter and sometimes by another to correct any initial direction error which might occur.

The following table gives the results for Maze 1:

TABLE 7

CHICKS 1, 2, 3, 4, 5, 6, 7, 8 AND 9 WERE NORMAL CHICKS. CHICKS 27, 29, 32, 33, 34 AND 35 WERE ALCOHOL CHICKS

	Trial				
No. of Chick	1	2	3	4	5
1	7′ 15 ″	21 ″	2′ 27 ″	5 ″	4.8″
2	6′ 45 ″	26.2″	2′ 7 ″	38 ″	18 ″
3	1′ 9.4″	20.6″	8.4″	10 ″	10 ″
4	1′ 28.8″	30.8″	18.4″	7.2″	9 ″
5	12 ″	8′ 8.8″	6.8″	5.2″	3.6″
6	15.6″	15.6″	52.6″	5.2″	5 ″
7	1′ 15.6″	11.6″	5.2″	3.2″	21.2″
8	23.8″	38.8″	36 ″	24 ″	14 ″
9	3′ 51.6″	14 ″	27.8″	10.2″	11.2″
Average	2′ 30+″	1′ 14+″	44+″	12+″	10+″
27	27 ″	9 ″	8″	9 ″	11.2″
29	30.6″	8.4″	4.2″	4.4″	3.6″
32	32.2″	6 ″	7 ″	3 ″	4.2″
33	8′ 35.4″	8 ″	1′ 20 ″	2′	16.4″
34	12.4″	8 ″	7 ″	10.4″	7.4″
35	11′ 23 ″	8′ 5 ″	2′ 1 ″	55 ″	46 ″
Average	3′ 36+″	1′ 27+″	37+″	33+″	14+″

TABLE 7—*Continued*

No. of Chick	Trial 6	7	8	9	10
1	10.5″	6.5″	11.5″	3.8″	4 ″
2	9.8″	21 ″	28 ″	18.8″	45.2″
3	9 ″	12 ″	10.8″	6 ″	12.4″
4	11 ″	13.6″	13.2″	12.4″	9.4″
5	2.6″	2.8″	2 ″	2.8″	3.4″
6	3 ″	7 ″	5 ″	4.8″	4.4″
7	15 ″	18 ″	26.6″	8.6″	23.2″
8	9 ″	4 ″	4.2″	4.2″	11.6″
9	9.6″	9.4″	24 ″	9 ″	13.6″
Average	8+″	10+″	13+″	7+″	14+″
27	4 ″	2.8″	4 ″	5 ″	3.2″
29	3 ″	4.6″	4.2″	2.8″	3 ″
32	9 ″	8 ″	16 ″	8 ″	9 ″
33	8 ″	15.6″	17 ″	8.2″	23. ″
34	6.8″	5 ″	6 ″	10.8″	10.6″
35	29 ″	15.2″	24 ″	27 ″	16 ″
Average	9+″	8+″	11+″	10+″	10+″

Maze No. 2

Maze 2 was a simple choice maze, consisting of one straight alley with two slightly shorter alleys running at right angles to it. The right hand alley ended blindly. The left hand alley was open, permitting the chick to jump to the box in which its companions were kept. The maze stood on a table, the edge of which was six inches above the box.

The subjects of the first experiment with this maze were six normal and six alcohol chicks of the second set. The procedure was the same as that used with Maze 1.

The difference in the behavior of normal and alcohol chicks was more pronounced in these tests with Maze 2 than in any of the other tests. It was thought at the time that this was due to the increased difficulty of the maze problem which emphasized differences in learning capacity. But later results with Maze 2 and with the still more complicated Maze 3 did not bear this hypothesis out. In these tests with Maze 2 the normal chicks with one exception, found the right path and thereafter chose it. One chick chose the wrong alley on the second trial and went half way to the end, then turned and chose the right path. The normal chicks which went to the box slowly did so because they stopped and pecked at the bright nail heads with which the strips where the alleys joined were studded.

All of the alcohol chicks made two or more wrong choices after the first trial. Several tried to peck their way through the side and two tried repeatedly to fly out at the back though they had several times found the path to the box. There is not one instance of this kind of behavior in the case of the normal chicks of this set. Two of the alcohol chicks went to sleep and had to be prodded repeatedly.

No. 27, whose record in Maze 1 was as good as that made by the normal chicks, found the right path, chose it three times in succession, made one wrong choice in each of the three following trials, went straight to the box in the seventh, eighth and ninth trials, then hesitated a long time before making a choice on the tenth trial.

Alcohol No. 35 failed to find its way out of the maze. The first trial it was slowly pushed to the entrance at the end of twenty-five minutes. After an interval of thirty seconds, during which it was allowed to feed with the other chicks, it was replaced in the maze. At the end of twenty-five minutes, during which it had repeatedly gone to sleep, it was replaced with the other chicks.

The following table gives the results in detail:

TABLE 8

CHICKS 1, 2, 3, 4, 6 AND 8 WERE NORMAL CHICKS. CHICKS 21, 22, 28, 29, 32 AND 35 WERE ALCOHOL CHICKS

No. of Chick	Trial 1	2	3	4	5
1	4′ 41.2″	40.2″	11.2″	2 ″	1.8″
2	4′ 20 ″	42 ″	13.6″	13 ″	2.2″
3	32.2″	18.6″	3 ″	4 ″	3.9″
4	6 ″	5 ″	4 ″	2.2″	2 ″
6	9′ 1 ″	1′ 35 ″	3′ 52 ″	1′ 13 ″	2′ 10 ″
8	3′ 22 ″	33 ″	10 ″	4 ″	3.6″
Average	3′ 40+″	38+″	45+″	16+″	23+″
21	1′ 59 ″	16 ″	20 ″	4 ″	5 ″
22	2′ 30 ″	32.8″	50.6″	15 ″	24 ″
28	39.9″	8.6″	16.4″	16 ″	6 ″
29	20′ 23 ″	6′ 42 ″	30 ″	17 ″	20.2″
32	19′	5 ″	15 ″	4.4″	3.6″
35	Failed				
Average	5′ 34+″	1′ 32+″	26+″	11+″	11+″

TABLE 8—*Continued*

No. of Chick	Trial 6	7	8	9	10
1	2 ″	3 ″	1 ″	.9″	1 ″
2	2.8″	1.4″	2.4″	1 ″	2 ″
3	3 ″	4″	5 ″	18.6″	2 ″
4	2 ″	2.4″	5 ″	4 ″	
6	2′ 2.5″	4 ″	6.8″	2.8″	3.4″
8	5.8″	4.4″	2 ″	5 ″	5 ″
Average	23+″	3+″	3+″	5+″	2+″
21	6 ″	4 ″	10.4″	5 ″	2 ″
22	18 ″	4 ″	4.8″	9.4″	4.4″
28	15 ″	9 ″	11.8″	5 ″	5.8″
29	5 ″	18 ″	5 ″	13 ″	4.6″
32	3 ″	2.8″	3 ″	6.4″	2 ″
35			Failed		
Average	9+″	7+″	7+″	7+″	3+″

The second experiment with this maze was made on the chicks of the fifth hatching, consisting of six normal, four hole, six water and five alcohol chicks. The procedure was like that used with Maze 1.

The following table gives results in detail:

TABLE 9

CHICKS 2, 3, 4, 6, 10 AND 14 WERE NORMAL CHICKS. CHICKS 20, 21, 23 AND 25 WERE HOLE CHICKS. CHICKS 41, 43, 46, 47, 48 AND 51 WERE WATER CHICKS. CHICKS 71, 72, 74, 80 AND 81 WERE ALCOHOL CHICKS.

No. of Chick	Trial 1	2	3	4	5
2	2 ″	3 ″	3.5″	5 ″	5.5″
3	9 ″	6.5″	7 ″	15 ″	8 ″
4	58 ″	10.5″	4 ″	14 ″	3 ″
6	4′ 1.5″	13 ″	4′ 47 ″	19 ″	31 ″
10	4 ″	2 ″	2.5″	3.5″	4.5″
14	30 ″	39 ″	4.5″	6 ″	8.5″
Average	57+″	12+″	51+″	10+″	10+″
20	1′ 48 ″	10 ″	15 ″	4.5″	3.5″
21	35 ″	21 ″	12.5″	14.5″	11 ″
23	15 ″	31 ″	15 ″	10 ″	5 ″
25	5′	11.5″	26.5″	4 ″	4.5″
Average	3′ 24+″	18+″	17+″	8+″	6+″

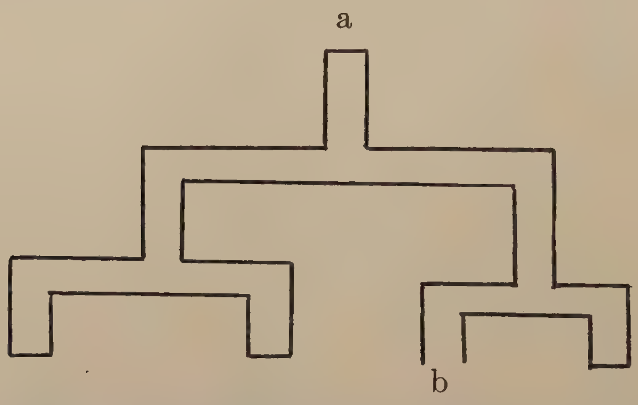
TABLE 9—*Continued*

No. of Chick	Trial 1	2	3	4	5
41	1′ 3 ″	14 ″	12 ″	5 ″	3.5 ″
43	8′ 5 ″	10′ 42 ″	18 ″	4 ″	4 ″
46	1′ 35 ″	47 ″	25 ″	23 ″	21 ″
47	55 ″	17 ″	22 ″	12 ″	10 ″
48	7.5″	22 ″	5 ″	4 ″	2.5″
51	17.5″	1′ 2 ″	7 ″	35 ″	13 ″
Average	2′+	2′ 12+″	16+″	13+″	9+″
71	10 ″	4 ″	9 ″	12 ″	10 ″
72	12 ″	8 ″	5 ″	6 ″	47 ″
74	1.5″	11 ″	16 ″	9 ″	9.5″
80	6 ″	9′ 2 ″	8 ″	5 ″	3.5″
81	43 ″	22 ″	8.5″	10 ″	7 ″
Average	12+″	1′ 57+″	9+″	8+″	15+″

No. of Chick	Trial 6	7	8	9	10	No. of wrong turns
2	7.5″	13 ″	6.5″	5 ″	13 ″	0
3	22 ″	5.5″	8 ″	11.5″	13.5″	0
4	7 ″	3.5″	3 ″	3 ″	3 ″	1
6	8.5″	7 ″	18 ″	7 ″	18 ″	1
10	6.5″	4 ″	5 ″	3 ″	7.5″	0
14	3.5″	3 ″	3 ″	6 ″	6 ″	2
Average	9+″	6+″	7+″	5+″	10+″	
20	6 ″	4 ″	6.5″	3 ″	3 ″	0
21	33.5″	11 ″	24.5″	44 ″	24 ″	0
23	22 ″	11 ″	?	45 ″	7 ″	?
25	1′ 27 ″	7 ″	17 ″	9.5″	4 ″	0
Average	47+″	8+″	?	27+″	9+″	
41	10.5″	3 ″	4 ″	8 ″	9 ″	0
43	12 ″	3 ″	4 ″	5 ″	4 ″	1
46	11 ″	6.5″	15 ″	19 ″	17 ″	?
47	17 ″	13 ″	20 ″	4 ″	9 ″	1
48	2.5″	2.5″	2.5″	3 ″	2.5″	1
51	7.5″	1′ 13 ″	25 ″	7 ″	8 ″	2
Average	10+″	15+″	11+″	7+″	8+″	
71	15 ″	20 ″	6 ″	13 ″	21 ″	3
72	1′ 17 ″	10 ″	4′	1′ 40 ″	7′ 6 ″	0
74	8 ″	17 ″	12.5″	19 ″	8.5″	2
80	4.5″	3 ″	3 ″	3 ″	5 ″	1
81	3 ″	5 ″	4 ″	5 ″	15 ″	0
Average	21+″	11+″	53+″	28+″	1′ 15+″	

Maze No. 3

Maze 3 consisted of a series of short, straight alleys arranged in the following pattern:



a was the point at which the chick was placed in the maze.
b was the open exit where the chick emerged at the edge of the table holding the maze and ran down a short incline into the chick pen ten inches below the table edge.

The chicks used with this maze were those of the fifth hatching. Each chick was given thirty successive trials without interval. The problem appeared to be as difficult as it could be and still be solved by the normal chicks. But even here the hole, water and alcohol chicks were at a disadvantage only during the earlier trials. Their records for the last ten trials are as good as those of the normal chicks.

Certain of the chicks of this hatching made little or no improvement in the course of the tests with Maze 2. These were chicks 10, 21, 51, 71 and 72. Chick 21 died before the tests with Maze 3 were begun. Of the others the only one which did not make a record which showed the normal rate of improvement in Maze 3 was chick 10, a normal chick. Chick 43 was the only other chick whose behavior was unusual in both mazes. This chick was amazingly sluggish during the early trials in Maze 2. Its record for that maze is entirely normal, however, in its improvement as the trials progressed. This sluggishness was not apparent in Maze 3 but the time record increases instead of decreasing gradually as the trials progress.

Chick 43 was a water chick. Alcohols 71 and 72, who made very bad records in Maze 2, both made excellent records in Maze 3. Water 51, although slow in Maze 3, showed a distinctly normal rate of improvement. If consistent inability to decrease the time in running a maze is any indication of inability to acquire a new co-ordination then our results would indicate that the only chick we had which showed such inability was one hatched from an egg any unusual characteristic of which we were neither responsible for nor cognizant of.

The following table gives the results for Maze 3.

TABLE 10

Chicks 2, 4, 10 and 14 Were Normal Chicks. Chicks 20, 23 and 25 Were Hole Chicks. Chicks 41, 43, 46, 47, 48 and 51 Were Water Chicks. Chicks 71, 72, 74, 80, and 81 Were Alcohol Chicks.

No. of Chick	Trial 1	2	3	4	5	6
2	2′ 15 ″	38 ″	30 ″	38 ″	25 ″	31 ″
4	42 ″	1′ 2 ″	12 ″	50 ″	44.5″	27 ″
10	10 ″	11 ″	28 ″	17 ″	10.5″	10 ″
14	1′ 1.5″	41 ″	4 ″	16 ″	27 ″	21 ″
Average	1′ 2+″	38 ″	18+″	30+″	26+″	22+″
20	13′	32.5″	52 ″	14′ 16 ″	31 ″	13 ″
23	33 ″	55 ″	18 ″	45 ″	1′ 55 ″	1′ 4 ″
25	1′ 7 ″	1′ 34 ″	8.5″	28.5″	1′ 36 ″	1′ 7 ″
Average	4′ 53+″	1′+	26+″	5′ 9+″	1′ 20+″	48+″
41	34 ″	27 ″	2′ 44 ″	6′ 46 ″	43.5″	2′ 24 ″
43	33 ″	8 ″	25 ″	29 ″	16 ″	16 ″
46	1′ 19 ″	41.5″	2′ 1.5″	44 ″	1′ 37.5″	47 ″
47	3′ 20 ″	43 ″	17 ″	38 ″	25 ″	42 ″
48	28 ″	25 ″	2′ 30.5″	50 ″	33.5″	7 ″
51	1′ 9 ″	2′ 50 ″	29 ″	6′ 11 ″	20 ″	9 ″
Average	1′ 13+″	52+″	1′ 24+″	2′ 37+″	39+″	44+″
71	33.5″	10.5″	25 ″	5 ″	27 ″	11.5″
72	5′ 30 ″	8′ 7 ″	5′ 16 ″	5′ 57 ″	3′ 12.5″	3′ 28 ″
74	17 ″	53.5″	43 ″	51 ″	25.5″	3′ 34 ″
80	48 ″	8.5″	5 ″	12 ″	9 ″	4.5″
81	22 ″	14 ″	51 ″	18 ″	1′ 28 ″	41 ″
Average	1′ 30+″	1′ 54+″	1′ 28+″	1′ 28+″	1′ 8+″	1′ 35+″

TABLE 10—*Continued*

	Trial					
No. of Chick	7	8	9	10	11	12
2.	1′ 21″	43″	1′ 11″	13″	30″	18″
4.	20″	1′ 52″	37″	58.5″	1′ 2.5″	27″
10.	11″	4″	9″	3″	4″	12″
14.	23″	40″	13.5″	8.5″	9″	20″
Average.	33+″	49+″	32+″	20+″	26+″	19+″
20.	42″	46″	7″	9″	7.5″	12″
23.	59″	49″	1′ 45.5″	40.5″	25″	1′ 12″
25.	18.5″	36″	30″	6″	5″	13″
Average.	39+″	43+″	47+″	18+″	12+″	32+″
41.	1′ 1″	15″	7″	6″	7″	7″
43.	13.5″	9.5″	14.5″	24.5″	34″	20.5″
46.	20″	59″	1′ 6″	12″	19″	25″
47.	36″	25″	1′ 29″	23.5″	33″	20″
48.	34″	10″	15″	12.5″	11″	20″
51.	11.5″	22″	18″	18″	21″	3′ 2″
Average.	29+″	23+″	34+″	16+″	20+″	45+″
71.	21″	11″	8″	58″	16″	4″
72.	1′ 1″	35″	55″	30″	1′ 1″	58.5″
74.	2′ 5″	16.5″	12″	16″	18.5″	19″
80.	5″	6″	7.5″	4″	43″	8″
81.	3′ 32″	1′ 13″	1′	7′ 53″	17″	1′ 19″
Average.	84+″	28+″	28+″	1′ 56+″	31+″	33+″

	Trial					
No. of Chick	13	14	15	16	17	18
2.	40″	39″	39″	50″	43″	1′ 23″
4.	7″	3′ 8″	25″	30″	22″	1′ 36.5″
10.	4″	18″	5″	24″	28″	10″
14.	29″	6″	7′ 52″	15″	14″	2′ 31″
Average.	20+″	1′ 2+″	2′ 15″	29+″	26+″	1′ 25+″
20.	1′ 27″	11.5″	38.5″	2′ 54″	10′ 56.5″	39″
23.	30″	3′ 4″	22.5″	35″	19″	27″
25.	22″	23″	25″	20″	21.5″	5.5″
Average.	46+″	1′ 12+″	28+″	1′ 16+″	3′ 52+″	23+″

TABLE 10—*Continued*

No. of Chick	Trial					
	13	14	15	16	17	18
41............	6.5″	7 ″	8 ″	7 ″	8 ″	7 ″
43............	16 ″	29 ″	24 ″	15 ″	12.5″	13 ″
46............	13 ″	15 ″	16 ″	15 ″	21 ″	19 ″
47............	30 ″	55 ″	13.5″	38 ″	1′ 23.5″	39.5″
48............	14 ″	4 ″	21 ″	5 ″	27 ″	11.5″
51............	1′ 26 ″	17 ″	1′ 51 ″	25 ″	16.5″	46.5″
Average.......	25+″	21+″	32+″	17+″	28+″	22+″
71............	5 ″	19 ″	4 ″	4″	16 ″	4 ″
72............	55 ″	39.5″	47 ″	38 ″	53.5″	22 ″
74............	15 ″	19 ″	51 ″	29 ″	42 ″	14 ″
80............	3 ″	3 ″	6 ″	6 ″	4 ″	3.5″
81............	32 ″	30 ″	2′ 6 ″	1′ 36 ″	19 ″	16 ″
Average.......	22+″	22+″	46+″	34+″	26+″	11+″

No. of Chick	Trial					
	19	20	21	22	23	24
2............	45 ″	21 ″	16.5″	58.5″	15 ″	15 ″
4............	1′ 4.5″	21.5″	21.5″	6 ″	9 ″	9 ″
10............	40 ″	12 ″	16 ″	19 ″	6.5″	7.5″
14............	30 ″	9 ″	5 ″	22 ″	6 ″	5 ″
Average.......	37+″	15+″	14+″	26+″	9+″	9+″
20............	6 ″	15 ″	9 ″	9 ″	7.5″	9 ″
23............	48 ″	1′	42 ″	24 ″	29 ″	29 ″
25............	19.5″	5 ″	5 ″	4 ″	4 ″	40 ″
Average.......	24+″	26+″	18+″	12+″	13+″	26+″
41............	16 ″	1′ 11.5″	10 ″	8 ″	6 ″	5 ″
43............	59 ″	1′ 33 ″	33 ″	25.5″	44 ″	1′ 5 ″
46............	8 ″	13 ″	16 ″	58. ″	1′	14 ″
47............	2′ 25 ″	18 ″	17 ″	15 ″	1′ 16 ″	1′ 36 ″
48............	5 ″	6 ″	6 ″	4 ″	5 ″	19 ″
51............	24 ″	3′ 23 ″	2′ 41 ″	12.5″	1′ 55 ″	14 ″
Average.......	42+″	1′ 7+″	40+″	20+″	51+″	35+″
71............	5 ″	3 ″	3 ″	11 ″	3 ″	18 ″
72............	43 ″	21 ″	46 ″	44 ″	45 ″	30 ″
74............	15 ″	26 ″	11 ″	9 ″	1′ 23 ″	14 ″
80............	13 ″	3.5″	7.5″	4 ″	4 ″	5 ″
81............	14 ″	16 ″	14 ″	10.5″	6 ″	16.5″
Average.......	18+″	13+″	16+″	17+″	28+″	16+″

TABLE 10—*Continued*

No. of Chick	Trial						No. of errors
	25	26	27	28	29	30	
2..........	9″	20″	18″	57.5″	49″	36″	21
4..........	24″	39″	1′ 8″	23″	28″	10″	26
10..........	28″	43″	26″	1′ 24″	53″	7″	14
14..........	11″	5″	27″	15″	9″	12″	19
Average.....	18+″	26+″	34+″	44+″	34+″	16+″	
20..........	7.5″	22″	29″	32″	7″	30.5″	13
23..........	43″	51″	18″	31″	4″	35″	20
25..........	5″	36″	24″	6″	6″	21″	20
Average.....	18+″	36+″	23+″	23+″	5+″	28+″	
41..........	5″	7″	6.5″	11″	9.5″	6″	8
43..........	21″	50″	30″	32″	53″	41″	23
46..........	12.5″	29″	28″	1′ 3″	23″	9″	21
47..........	8″	19″	19″	29″	23″	11″	12
48..........	5″	6″	4″	4″	10.5″	12.5″	16
51..........	1′ 43.5″	1′ 33″	1′ 13″	2″	36″	2′ 13″	8
Average.....	25+″	34+″	26+″	23+″	25+″	35+″	
71..........	6″	3″	10.5″	2.5″	3″	5.5″	14
72..........	1′ 21″	47″	1′ 38″	55″	45″	1′ 3.5″	29
74..........	10″	19″	26″	11.5″	23″	8″	14
80..........	5″	5″	4.5″	1′ 11″	14″	24″	11
81..........	8″	5″	4″	7″	4″	4″	18
Average.....	22″	15+″	28+″	29+″	17+″	21+″	

EXPERIMENTS WITH SENSORY DISCRIMINATION

The apparatus used for testing the ability of the chicks to make sensory discriminations was the Yerkes visual choice apparatus. Only the two middle alleys were used, the other two being shut off by wooden partitions. Stimulus screens with openings in them large enough to permit the chick to pass through were slipped into the grooves at each end of each alley. The screens were made of photographic mounting cardboard and two of them were light grey and two dark grey in color. The exit path in which the light grey screens were placed was always open and the chick choosing that path progressed directly out of the apparatus to the chicken pen and the society of the other chicks. The exit path characterized by the dark screens was always closed at the far end and the wires crossing the floor of the path were electrically charged so that the chick choosing that path received a slight shock and did not get out of the apparatus until it had gone back and found the other exit. The light screens were placed alternately in the left and right hand alley.

The chick to be tested was placed in the release box at the back of the apparatus and the wire screen which led to the paths was not lifted until the chick crowded against or pecked at it. No chick was ever left struggling in the release box. The chick was always allowed to find its way in time into the correct alley and out of the apparatus but its record for the trial depended on its first choice of exit paths. Each chick was given ten preference trials with both exits open and the wires not charged. The one chick which showed a preference was not used in these experiments. Chicks of the third hatching were used with this apparatus.

Six normal and five alcohol chicks were each given three trials a day for twenty-five days. Immediately after this normal No. 5 and alcohol No. 24 and six days later normal No. 13 and alcohol No. 33 were given thirty additional trials in succession. The records for the last fifteen trials at the end of the first seventy-five trials are as follows: one normal chick made 73⅓% correct choices; two made 60% correct choices; one made 46⅔% correct choices; one made 40% correct choices; one alcohol chick (No. 24) made 80% correct choices; two made 46⅔% correct choices; one made 33⅓% correct choices, and one made 26⅔% correct choices. The records for the last ten of the thirty additional trials given four of the chicks are as follows: normal No. 5 made 100% correct choices; normal No. 13 made 90% correct choices; alcohol No. 24 made 60% correct choices; and alcohol No. 33 made 40% correct choices.

Chicks of the fourth hatching were also used in this apparatus. These chicks were trained in pairs, each pair being composed of a normal and an alcohol chick. One normal chick was given a trial. Then an alcohol chick was given a trial. Then the normal chick was retested and the alcohol chick retested and so on. This procedure was continued until one of the chicks had made ten consecutive correct choices. Tests with that pair were then discontinued and tests with a new pair begun.

Normal No. 14 and alcohol No. 37 were each given 101 trials.

Normal No. 14's percentage of correct choices during the last ten trials was 100; alcohol No. 37's was 30. Normal No. 18 and alcohol No. 30 were each given 75 trials. During the last ten trials the normal chick's record was 100% correct choices and the alcohol's record was 50% correct choices. Normal No. 15 and alcohol No. 34 were each given 67 trials. The normal chick made a record of only 70% correct choices during the last ten trials whereas the alcohol chick made a record of 100%.

The alcohol chicks plainly formed the association more slowly than did the normal chicks and there were alcohol chicks which seemed unable to form the association in the time at our disposal for training them. But as in the experiment with the mazes there were individuals among the alcohols which did as well as normal chicks and there were normal chicks which did as badly as the alcohol chicks.

INHIBITION OF AN INSTINCTIVE REACTION

The apparatus used in this experiment was a large square of dark grey paper over which was placed a pane of glass the exact dimensions of the paper. On the paper under the glass were scattered bits of egg yolk. Ten chicks of the fourth hatching, five normal and five alcohol, were used in this experiment. The group of normal chicks was placed on the glass for five minutes each day and the total number of pecks of all five chicks was recorded. The chicks were then replaced in the box and the same procedure repeated with the group of alcohols. These tests were repeated for twenty-five days. There was no appreciable difference in the behavior of the two groups. The alcohol chicks learned to inhibit the reaction with approximately the same rapidity as the normal chicks.

The following table gives the number of pecks each group made on each of the trial days.

TABLE 11

	Day												
	1	2	3	4	5	6	7	8	9	10	11	12	13
No. of pecks made by normal chicks........	4	6	6	2	1	2	1	0	0	0	1	2	2
No. of pecks made by alcohol chicks........	4	6	6	1	3	0	1	0	4	0	0	0	1

TABLE 11—*Continued*

	Day 14	15	16	17	18	19	20	21	22	23	24	25	26
No. of pecks made by normal chicks........	0	1	2	1	2	4	2	5	1	1	0	0	1
No. of pecks made by alcohol chicks........	1	0	3	3	2	5	3	4	0	3	0	1	0

INHIBITION OF AN ACQUIRED REACTION

It will be remembered that the chicks of the fifth hatching were used in Maze 2. This maze was a reversible maze so constructed that after it had been used with the exit at one side it could be turned over and present the same problem, except that the exit would be at the other side, requiring the chick to turn in the opposite direction from that in which it had formed a habit of turning. Each chick of the fifth hatching was given ten trials in this maze (for record see Table 9) and immediately thereafter the maze was reversed and the chick given ten more trials. The chicks which failed successfully to inhibit the previously acquired reaction were normal chick No. 2 and alcohol chicks Nos. 74 and 80. Chicks Nos. 10, 21, 51 and 72 made very poor records but these chicks, it will be remembered, had never acquired the proper reaction in the maze during the first ten trials. They were equally unsuccessful when the maze was reversed. These four chicks, it will be noted, represent the four different groups of chicks obtained in this hatching. In the matter of inhibiting an acquired reaction these results seem to give no pronounced advantage to any group of chicks.

The following table gives the results for Maze 2 reversed:

TABLE 12

CHICKS 2, 3, 4, 6, 10 AND 14 WERE NORMAL CHICKS. CHICKS 20, 21 AND 25 WERE HOLE CHICKS. CHICKS 41, 43, 47, 48 AND 51 WERE WATER CHICKS. CHICKS 71, 72, 74, 80 AND 81 WERE ALCOHOL CHICKS

No. of Chick	Trial 1	2	3	4	5
2......................	8.5″	18 ″	8.5″	10 ″	7.5 ″
3......................	1′ 34.5″	26.5″	10.5″	10 ″	19 ″
4......................	2 ″	2 ″	4 ″	3 ″	3.5″
6......................	6′ 42.5″	17 ″	3′ 28 ″	39 ″	26 ″
10......................	16.5″	3 ″	13 ″	4 ″	14.5″
14......................	4 ″	2 ″	3 ″	2.5″	2 ″
Average.................	1′ 28+″	11+″	41+″	11+″	12+″

TABLE 12—*Continued*

No. of Chick	Trial				
	1	2	3	4	5
20	1′ 3 ″	37 ″	13 ″	15 ″	13 ″
21	51.5″	37 ″	15.5″	33 ″	2′ 54 ″
25	12′ 57 ″	2′ 45 ″	1′ 54 ″	8 ″	21.5″
Average	4′ 57+″	1′ 19+″	47+″	18+″	1′ 9+″
41	27.5″	28 ″	9 ″	29 ″	8 ″
43	9 ″	8 ″	5 ″	12 ″	24 ″
47	1′ 3 ″	10 ″	34 ″	18 ″	16 ″
48	4′ 51 ″	10 ″	10 ″	4 ″	16 ″
51	25 ″	30 ″	13 ″	6.5″	8.5″
Average	1′ 23+″	17+″	14+″	13+″	14+″
71	20 ″	8 ″	3 ″	5 ″	6 ″
72	30 ″	21 ″	45 ″	17 ″	8′ 15 ″
74	12.5″	6 ″	5.5″	5 ″	11 ″
80	5 ″	13 ″	15.5″	7 ″	17 ″
81	7′ 12 ″	1′ 4.5″	14 ″	11 ″	5 ″
Average	1′ 38+″	22+″	16+″	9+″	1′ 46+″

No. of Chick	Trial					No. of wrong turns
	6	7	8	9	10	
2	19 ″	7 ″	19 ″	8 ″	31 ″	10
3	15 ″	6 ″	10 ″	12.5″	9.5″	0
4	3 ″	4 ″	2.5″	3.5″	3 ″	0
6	8 ″	6 ″	5 ″	1′ 3 ″	13.5 ″	3
10	4.5″	15.5″	15.5″	6.5″	25 ″	2
14	3.5″	2 ″	2.5″	5 ″	2 ″	0
Average	8+″	6+″	9+″	16+″	14+″	
20	13 ″	28 ″	14.5″	17.5″	10 ″	2
21	35 ″	21.5″	3′ 10 ″	31 ″	46.5″	3
25	6.5″	45 ″	5.5″	5.5″	5 ″	3
Average	18+″	31+″	1′ 10+″	18+″	20+″	
41	13 ″	23 ″	20 ″	7.5″	19.5″	4
43	14 ″	10 ″	32 ″	8 ″	9 ″	6
47	20 ″	8 ″	19 ″	4 ″	8 ″	2
48	12 ″	17 ″	9 ″	4 ″	12 ″	6
51	36 ″	16 ″	43 ″	1′ 40 ″	37.5″	2
Average	19+″	14+″	24+″	24+″	17+″	
71	4 ″	5 ″	9 ″	3 ″	4 ″	1
72	6′ Became so inactive the experiment had to be dropped.					5
74	3.5″	8 ″	12 ″	8 ″	12.5″	0
80	13 ″	6 ″	17 ″	23 ″	4.5″	1
81	4.5″	4 ″	3.5″	20 ″	10 ″	1
Average	1′ 15+″	5+″	10+″	13+″	7+″	

CONCLUSIONS

1. Chicks are neither positively or negatively phototropic. Some show what appears to be an instinctive positive response to light on the first but not on the second and third day; some on the second but not on the first and third day; a few not until the third day and some not at all.

2. Imitation plays no part in the perfecting of the pecking reaction of either normal or alcohol chicks.

3. It is possible by tampering with eggs before the hatching of chicks to modify the behavior of the chicks in the following ways; on the fifteenth day they do not show the caution in jumping from heights which chicks hatched from normal eggs show all the time and which the chicks hatched from abnormal eggs show earlier than the fifteenth day; they are less likely than normal chicks to react to a maze situation with general motor activity and consequently are slower in beginning to acquire the consequent motor co-ordination though they may eventually acquire it in the same number of trials required for a normal chick; they are slower in acquiring an association depending on sensory discrimination in the Yerkes visual choice apparatus; the instinctive reactions of pecking and drinking apparently remain unmodified; the processes of inhibition of both instinctive and acquired reactions seem to be alike in normal and abnormal chicks.

4. It is not possible to find any difference between the instinctive reactions of pecking or between the modifications of the acquiring of reactions in the maze in the case of chicks raised from eggs into which alcohol has been injected by our method, and chicks raised from eggs into which distilled water has been injected or eggs which have had the shell perforated and sealed. That is, alcohol, *per se*, seems to have no specific effect beyond an effect which can easily be explained by malnutrition during hatching and which may be as readily produced by other agents as by alcohol.

DEATH FEIGNING REACTIONS IN *TYCHIUS PICIROSTRIS*

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The behavior of the lower organisms is of importance, not only for the intrinsic interest attached to the study of the subject but also for the light which it may throw on the more complicated reactions of the higher organisms. Any contributions, therefore, which will add to our knowledge of any phase of animal behavior or confirm results already obtained in this field, which has not been greatly exploited, will be of some interest to the student of comparative psychology; and for this reason the writer is publishing the following brief notes on observations incidentally made while studying the habits of *Tychius picirostris*, an European weevil observed this year for the first time in this country doing appreciable injury to clover.

The habit of feigning death is found in a large number of animals but is most marked in certain insects. This habit among insects is of interest not only to the student of behavior but also to the collector and to the applied entomologist. The entomological collector often takes advantage of this reaction in collecting beetles and other insects which fall to the ground in a death feint when a sudden jar is given to the plant on which they are feeding, and this practice of jarring has been used effectively in the control of certain insect pests such as the May beetles (*Lachnosterna* spp.) and the plum curculio (*Conotrachelus nenuphar* Herbst), especially prior to the advent of arsenical sprays.

Methods of Producing the Feint. The weevils congregate in large numbers on the leaves of the clover in the spring, and on the flower heads later in the season. If a plant attacked by these weevils is jarred, the majority of the insects will fall to the ground. Their action upon falling shows considerable individual variation; most of those which fall on their backs will assume the death feigning attitude for a few seconds, and, on recovery, turn over and either scramble away immediately or remain quiescent for a brief period before moving away. A few of those which fall on their backs will not feign death but will turn over and move away at once.

Of those which fall to the ground right side up some will remain quiet for a short time with their legs in the normal resting position, others will run away immediately on reaching the ground but very few will assume the typical death feigning attitude.

In the laboratory the feint was obtained in one of three ways: by dropping the insect on the desk, by pinching it lightly with a forceps or by merely turning it on its back. The last method was usually successful in evoking the death feigning response and was generally employed. After remaining in the feint for a variable period the insect relaxes its legs and struggles to turn over. On turning over, or on being turned over the insect scrambles away, but while it is running it may be induced to feign a second time by again turning it on its back, and within certain indefinite limits to be indicated below this process may be repeatedly successful.

While struggling on its back the insect may be induced to feign death by tapping it on the sternum. If, however, it is in the normal position, with its back turned up it will not feign death on being tapped on the back; on the contrary a quiescent insect thus treated will become active.

The intensity of the shock seems to have no effect on the production or duration of the death feint, as an insect which has been merely turned over, or dropped from a height of six inches remains in the death feint as long as one dropped from a height of eight feet or more. It was also found that if the feint could not be elicited by overturning the insect or by dropping it from a height of six inches or thereabouts, it was impossible to produce it by dropping from greater heights up to eight feet, or even by lifting with forceps and forcibly dashing to the table.

It was found impossible to obtain the death feigning reaction with some individuals. As the insects experimented on had matured some time previous to the period of these investigations and had not been under constant observation from the time of eclosion it is not possible to say whether these individuals always reacted negatively, or from what cause they had lost the power of response.

Death Feigning Attitudes. The attitude typically assumed by the insect during the death feint is not a simulation of the attitude of the dead insect. In death the femora are always extended more or less perpendicularly from the ventral surface of the body, and are never pressed against the sternum, even if the insect is killed when in the feigning attitude. The tibiae and tarsi are flexed in such a way that the latter are often more or less intertwined and always quite close to each other. In the death feigning attitude the legs are all pressed closely against the sternum and the tarsi are never very close to each other. The fore femora extend straight out laterally, pressed against the prosternum, the tibiae are bent back against the ventral face of the femora and the tarsi are bent forward and outward. The middle femora also extend laterally and slightly forward, the tibiae bend caudo-mesad, their apex being situated in front and to one side of the meta-coxae. The tarsi run either straight or obliquely backwards. In the hind legs the femora are stretched obliquely backwards, the tibiae bent forward almost parallel to

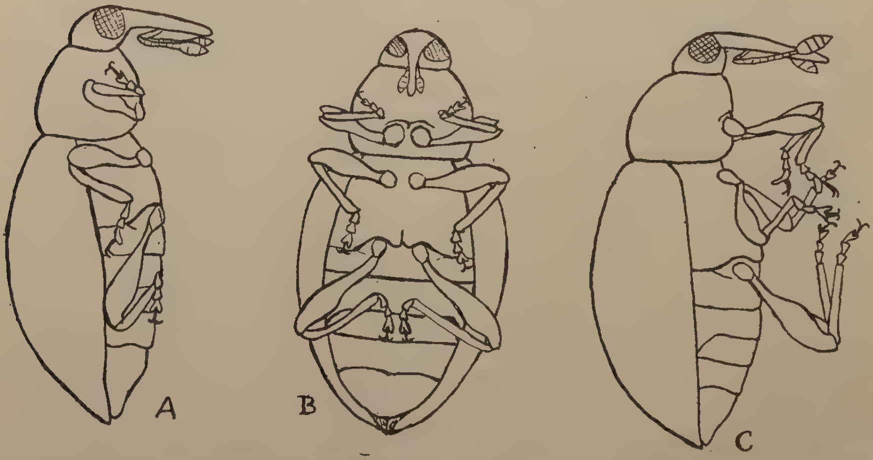

FIGURE 1.—Death-feint of *Tychius picirostris*. A and B, lateral and ventral views of the death-feigning attitude. C, lateral view of the insect after death. ×21

the femora and the tarsi bent backwards. The rostrum is almost perpendicular to the body and the antennae are folded together behind the rostrum.

Often the insect becomes quiescent on being stimulated, without assuming the attitude described in the foregoing paragraph. In such cases it may remain perfectly still with the legs outstretched or partially and asymetrically flexed. This attitude I have termed the partial feint and it will thus be referred to when necessary to distinguish it from the typical feint. Sometimes the insect when stimulated assumes the typical death feigning attitude, but after a while it slowly relaxes its legs without becoming active. Usually but not invariably the partial feint is manifested after the insect has been repeatedly stimulated. It is therefore probable that the failure to flex the legs is due to muscular fatigue.

Variability of the Feigning Response. The feigning response to tactual or shock stimuli is not stereotyped as there exists a considerable range of variability in the duration of the feint, not only in the different individuals but in the same individual in successive feints. In some cases too, as stated above, I found it impossible to evoke the feigning response by any means. The reaction of mutilated specimens was also not constant owing no doubt to slight differences in the sensitiveness of the nervous system which would influence the intensity of the shock effects of mutilation. While any general statement made is based on the results of the reaction of the majority of individuals, the number failing to give the typical response was in some cases considerable, and for this reason special attention is called to the fact here.

As to the exact cause of this variability I am unable to give a positive explanation. Probably, however, it is not wholly due to the inherent individuality of the specimens but partly to the varying "experiences" of the individuals. If the insects had been kept under the same conditions from the time of their eclosion it is probable that the reactions would be more nearly uniform, or where a wide variability exists there would be an evident explanation.

Duration of the Death Feint. The duration of the feint at room temperature is usually very short, the insect recovering almost invariably before the expiration of a minute. The longest feint obtained in these experiments lasted for seven minutes and twenty seconds. This case was unique, but occasionally feints lasting over a minute or even as long as two minutes were obtained. There seems to be no definite relation between the durations of successive feints. They are not gradational nor do they vary proportionately in any two individuals examined.

TABLE I

Duration in Seconds of Ten Successive Feints of Seven Individuals

	1	2	3	4	5	6	7	8	9	10	Average
B.........	15	11	22	15	15	10	5	0	3	10	10.6
C.........	5	10	15	14	6	11	9	18	10	7	10.5
D.........	12	7	440	36	31	10	277	2	4	32	85.1
E.........	10	8	20	7	15	48	15	0	3	20	14.6
F.........	*0	125	10	13	40	25	8	30	28	20	29.9
G.........	30	60	6	6	10	35	25	20	5	3	20.0
I.........	*0	*0	†3	0	†4	16	†80	18	15	15	15.1
Average...	10.3	31.6	73.7	13.0	17.3	22.1	59.9	12.6	9.7	15.3	26.5

* Failure to respond to stimulation.
† Partial feint.

Effects of Repeated Stimulation on the Death Feint. Experiments were conducted to determine whether the death feint could be induced indefinitely by repeated stimulation. It was found that the feint could not be elicited indefinitely, but the number of times that it could be elicited before the insect ceased to respond varied considerably with different individuals. In some cases the insect would feign death only a few times and then refuse to respond further, and in no case was I able to elicit more than forty successive feints. The results of other workers may be of interest in this connection. " Holmes found in the case of ten *Ranatras* successively put into death feints that these were continued without interruption from 9 a. m. to 5 p. m., when the last specimen refused to feign longer. The Severins found it possible in the case of *Belostoma* to induce feints successively for a total of five hours. The responses of the curculio (*Conotrachelus nenuphar* Herbst.) were very much less pronounced than was the case of these forms. Feints could not be elicited successively for a period of greater length than two hours, fifty-three representing the largest number of feints successively produced in a single individual."[1]

The results obtained with *Tychius picirostris* did not differ markedly from those of Gee and Lathrop with the plum curculio, but the period during which the feint could be successively elicited was not so great, varying from a few minutes to somewhat over an hour.

Repeated stimulation results in a reduction of the average duration of the feints, although the duration of one of the later feints may be greater than that of some occurring earlier in the succession. The following table gives the average duration of the first ten feints of four individuals as compared with that of all succeeding feints. In computing the averages, cases in which the insects did not respond are omitted. If these were included the average duration of the later feints would be much lower.

TABLE II

AVERAGE DURATION (IN SECONDS) OF EARLIER AND LATER FEINTS

	D	F	G	I
First ten feints	85.1	29.5	20.0	27.4
Feints after tenth	17.6	18.6	5.7	9.5

There is a certain irregularity to be noted in the later feints. With few exceptions, in cases where a long succession of feints was obtained, the first several attempts to produce the feint were successful. Later, however, the number of unsuccessful attempts increased until finally the point was reached at which the feint could no longer be elicited.

When the limit of successful response was reached the method of producing the shock stimulus was changed to discover whether this would have any effect in inducing the feint. It was found that in most cases either the insect did not respond, or it responded in the first few trials only. Only in one case did I succeed in obtaining a long succession of feints by changing the method of evoking the feint after the insect had failed to respond to the first means employed, and in this case seventy-six per cent were partial feints.

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[1] Gee and Lathrop. Death Feigning in *Conotrachelus nenuphar* Herbst. *Annals Entomological Society of America,* 1912, **5**, 391-399.

Another question which suggested itself was whether the insect would recover its sensitiveness if allowed to rest. It was found that after one or two hours' rest the reaction was in general similar to that obtained by changing the method of producing the shock, except that there was a larger number of fairly long successions.

The history of the three following cases will serve to illustrate more definitely some of the points discussed in this section:

*D*1. Left for an hour after the fourteenth feint. On resuming the experiment, the first four trials were successful; of the six next, three were successful and after this there was a long series of failures with an occasional success. The method of inducing the feint was then changed and the insect dropped on its back instead of being merely turned over. In the first eight attempts there were five successes but after this, repeated endeavor could elicit no response.

*E*1. The feint was produced immediately by the first seven attempts. The fifteen following elicited the feint eight times, and after that the insect feigned death only twice in twenty trials. The method of producing the shock was changed and the insect feigned three times in the first ten trials.

I. In the first forty-five trials there were thirty-three successes and after this a long succession of failures. The insect was left for an hour and the trials were then resumed. The first three attempts were successful, but after these twenty successive attempts elicited no response. A change in the method of stimulating the feint resulted in the production of several partial feints but few perfect responses.

During the feint the muscles of the legs are very tensely contracted and Gee and Lathrop suggest that muscular fatigue eventually occurs as a result of this contraction, thus explaining in part the failure to elicit indefinite response.

Effect of Mutilation on the Death Feint. Several specimens were placed in the death feint and while in this condition portions of some or all of the legs were snipped off. In most cases the insect remained in the feint, either making no response or slightly twitching the legs. Sometimes, however, the insect became active on being dismembered. In some cases in which the insect was in a partial feint the shock of removing the tarsi induced a perfect feint.

Removing the antennae of the feigning insect almost invariably met with no response, the weevil remaining perfectly quiescent. Individuals with the antennae and legs mutilated could always be induced to feign again.

Snipping off the beak always resulted in renewed activity on the part of the subject except in one case, when the four tarsi, both antennae and the rostrum were successively removed without any manifestation of activity. It was found impossible to induce the feint until some time after the mutilation, when the shock effects of the operation had passed away.

Cutting away the tip of the abdomen always caused the insect to cease feigning. Insects thus mutilated, however, could usually be induced to feign again, though often with more difficulty than in the case of the normal individuals.

Insects divided between the thorax and abdomen or between the pro- and meso-, or meso- and meta-thorax always responded by coming out of the death feint. The hinder portion could not again be induced to feign death. In fact it did not live very long after being cut off. The anterior portion, however, gave the death feigning response but the threshhold of stimulation was raised by the mutilation for it was necessary to drop it to the table several times, or to tap it several times on the sternum before the death feint could be elicited. In this connection it may be advisable to state that only individuals which reacted readily previous to mutilation were used in these tests.

Decapitation invariably results in a feverish activity of the limbs. The legs are worked to and fro, and the tarsi rubbed against each other. At room temperature it was found impossible to obtain the feigning reaction with decapitated individuals. This is probably due to the shock effects of the very violent disturbance in the central nervous system caused by the mutilation, and not to any direct control of the supra-oesophageal ganglion over the death feigning reaction.

The results obtained with *Tychius picirostris* agree in general with those obtained by other workers.

Influence of Temperature on the Death Feint. Heat.—Insects feigning death were placed on their backs on a warm iron plate, the temperature of which was not high enough to be unbearable to the tips of one's fingers. Without a single exception the insects immediately became active and attempted to turn over and escape. It was impossible to produce the feint by dropping the insect on the hot surface. When the plate became cooled to a temperature slightly above that of the room, the feint, however, could be induced without difficulty. Insects dropped several times alternately on the warm plate and on the surface of the table feigned death in the latter case but would not on the heated surface.

Cold. Several individuals were placed in a refrigerator registering a temperature of 11° C. The feint could be very readily elicited and the duration was much greater than at room temperature. The duration of the initial feint varied from 55 seconds to 4 minutes and 35 seconds. The variability of the duration of successive feints was as marked as at room temperature, as may be seen from the following figures, which give the duration (in seconds) of the first five feints of one individual:

55, 40, 140, 385, 50

Other individuals were tested on a plate of thin glass placed on a block of ice. The feint lasted for periods ranging from nineteen minutes to upwards of an hour. At the end of an hour those which had not recovered spontaneously were removed to the table, where they immediately became active. On first being placed on the cold plate the insect becomes somewhat restive but does not actively struggle. After a short while the legs slowly and gradually relax, the degree of relaxation varying with the different individuals. In this condition the legs are never pressed against the body but their attitude resembles to some extent that of the limbs of the dead insect.

Cold alone, without mechanical shock, can produce a condition similar to that of the death feint. If an insect struggling on its back is placed on the cold glass plate it will after a while cease to struggle, become quiescent and assume a position similar to the feigning insects. This raises the question as to whether at low temperatures some other factor than those concerned in the production of the death feint does not come into play.

As stated above it was found impossible at room temperature to induce the feint in decapitated insects. Near the freezing point, however, the feint was evoked without difficulty. Under the microscope a slight twitching of the legs could be observed in the decapitated insect during the feint. On being removed to the table the insect resumed the twitching movements.

The anterior portion of weevils severed across the thorax also feigned death readily, and the duration of the feint was longer than at room temperature.

It will thus be seen that cold lowers the threshhold of stimulation and reduces the shock effects of mutilation.

These results agree closely with those obtained by Gee and Lathrop on *Conotrachelus nenuphar* Herbst and by Holmes on *Ranatra*.

Effect of Chloroform and Ether on the Death Feint. Insects feigning death were introduced into the vapor of chloroform and of ether. Chloroform seemed to have little effect on the duration of the first feint, but of fourteen individuals tested five could not be induced to feign a second time. The others with one exception could only be induced to feign death twice and this one exception was anaesthetised during the fourth feint.

TABLE III

THE EFFECT OF CHLOROFORM ON THE DURATION (IN SECONDS) OF FEINT, AND ON THE NUMBER OF SUCCESSIVE FEINTS OF FOURTEEN INDIVIDUALS

1	2	3	4	5	6	7	8	9	10	11	12	13	14
2,3	15	20	*15,4	4,9	15	30	11,14 20	8, 14	2,2	14,6	17	13,7	20,3

* Partial feint.

In three cases, stimulated by pinching with forceps while lying on their backs, it was found that the insects would draw up their legs to the feigning attitude, but relaxed them and resumed their struggles on being released from the forceps.

In the case of ether the results were different. A longer succession of feints could be obtained, but the ether had the effect of reducing the duration of the feints. While the number of successive feints was higher than was the case under the effect of chloroform it was not as high as was obtained under normal laboratory conditions. Only one individual feigned sufficiently often to be killed by the fumes of the ether.

TABLE IV

SHOWS THE AVERAGE DURATION IN SECONDS OF THE FIRST FEINT IN A LARGE NUMBER OF INDIVIDUALS UNDER NORMAL CONDITIONS AND UNDER THE INFLUENCE OF PHYSICAL AND CHEMICAL AGENTS

Normal	Heat	Cold (near 0° C.)	Chloroform	Ether
14.2	0	2020	13.3	5

The Nature of the Death Feigning Instinct. The death feigning instinct occurs in many widely different animals, even among certain birds and mammals. The advantage of the instinct to the possessor is a doubtful one. In the case of insects and other animals, the color of which resembles that of the natural environment, the power of feigning death is an additional safeguard against the prying eyes of the enemy. But in many cases the death feint is not only useless but may be positively injurious, so that the instinct cannot wholly be regarded as an advantageous adaptation, nor can its origin and subsequent evolution be accounted for on the grounds of usefulness to its possessor.

The instinct undoubtedly has its roots in some fundamental physico-chemical reaction of zooplasm. Holmes believes that in the amphipods the death feigning instinct has its foundation in the thigmotactic reactions common among these animals. The Severins also advance the theory that the reaction in *Nepa* and *Belostoma* is thigmotactic in nature. The results obtained with *Tychius picirostris*, in the writer's opinion, corroborate the theory that the physico-chemical reaction responsible for the manifestation of the death feint is of the same nature as that which calls forth the thigmotactic response of many insects and other animals and also of such plants as the *Mimosas* and other " sensitive plants." It must be borne in mind, however, that the statement that the death feigning instinct is thigmotactic in nature is an explanation which in turn needs to be explained, and a positive explanation is not yet forthcoming. It is probably due, however, to some disturbance in the balance of the metabolic processes causing the excessive elaboration of some substance or substances which incite the contraction of the leg muscles.

The feigning reaction may perhaps be resolvable into two components, one manifested in the flexing of the leg appendages, the other in the quiescence of the insect. The fact that it is possible to induce a partial feint in which the insect is perfectly quiet while the legs are not flexed and, in some cases, after treatment with chloroform, to induce the flexing of the legs unaccompanied by the quiescent state, suggests that these two actions may be the result of separable causes, but the data at hand are too slender for a definite pronouncement on the subject.

Attention should also be called to the fact that the reaction is segmental and not controlled by the supra-oesophageal ganglion. The fact that a decapitated insect will not react at room temperature is in no way antagonistic to this view, because the removal of some of the most important trophic centres must necessarily cause some disturbance in the metabolic processes of the nervous system, and the intensity of the stimulus necessary to bring about a definite reaction will differ from that necessary under normal conditions; in other words, the threshhold of stimulation may be either lowered or raised. One result of this disturbance is manifested in the pendulum and rhythmic movements of the legs of a decapitated weevil, and it it is obvious that this movement cannot coexist with the death feigning reaction as, from their natures, they are mutually exclusive. It will be remembered, however, that cold will so lower the threshhold of stimulation that the decapitated insect will respond readily at low temperature.

THE PHYSIOLOGICAL ANALYSIS OF BEHAVIOR[1]

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I

The facts of behavior make a manifold appeal. Among them all, those which seem especially to attract us pertain to the intricate game of human relations. Whether they take the form of premeditated words or unconscious deeds, elaborate rhetorical statements or direct emotional reactions, whether they suggest a soaring or a grovelling imagination, they challenge our powers of interpretation; they entice us into a search for their meaning. Attentive to their significance for us, we set up social standards, we develop moral codes, and we encourage a science of conduct that shall help us to formulate the courses of action we call ideals. We do all this that we may be the gainers thereby, somehow, somewhere, in the immediate present, the near or the distant future. Our motive is personal. We follow an impulse to self-preservation which reveals itself in all the races of mankind. Few individuals, indeed, are so thriftless as to fail to take some such thought, crude and sporadic though it may be, for the morrow. Explanations of some sort all but this exceptional and degenerate few must have. For primitive man, spirits and demons, naive myths and legends built on accidental circumstance suffice. For the children of civilization in large part, they suffice also. Nothing more dramatically proclaims the essential similarity of the peoples of the earth, however diverse in degree of savagery and sophistication, than the conservatism of their mythologies. It is but a few years since a most distinguished British statesman solemnly defended against scientific criticism the authenticity of the unclean spirits that entered into the Gadarene swine. Today whole nations are passionately associating their Gods and all the angels with their several contributions to the inconceivable violation of civilization that is now debauching Europe.

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[1] Read at Berkeley, California, before Section F, A. A. A. S., August 3, 1915.

II

These strange anachronisms are in striking contrast with current biological theory. Darwin's masterly argument for natural selection as a mechanical theory of adaptation banished forever from scientific speculation the doctrine of special creation according to Design, and established in its place an interest in the genesis of organic forms and functions according to natural law that has been of inestimable value in the interpretation of the world as we find it. With the publication of the "Origin of Species" appeared new aspects of fitness, new conceptions of conduct, a new and more practical ethic. The problems of behavior gradually assumed new forms under the influence of the comparative method. New light was thrown on questions of human right and wrong by investigations of the behavior of the lower organisms. Objective studies made head against pre-Darwinian types of speculation and the doctrine of natural selection was applied with increasing freedom to the elucidation of all sorts of organic response.

The adoption of a mechanical substitute for the crude teleology which natural selection displaced, marked an enormous advance in methods of investigation at the same time that it gave new meaning to problems of behavior. No mechanical theory of selection, however, is competent to explain the origin of the differences between organisms, their parts, or their actions, on which selection must be based. Such a mechanism of survival is insufficient because it represents results rather than processes. Even in the extreme form in which it appears in the theory of germinal selection, it remains external to the units selected. It is a logical, not a physiological mechanism.

III

It is to the analysis of physiological mechanisms that we turn, then, for further light upon the problems of behavior. At once questions of meaning take a new form. The significance of behavior, and its development, cease to be of immediate concern. For the objective of the physiologist is control of physiological processes, which is at once the pragmatic test of understanding and a practical necessity for the righteous life.

It is as a physiologist, then, that I invite your further attention to the problems of behavior. That we may see the fruits of physiological analysis against a background which will throw them into significant relief, it will be desirable first of all to consider the influence of selection theory on the physiological field.

Allusion has already been made to Weismann's application of selection theory to the problem of variation, which as the theory of germinal selection marks its extreme development in this direction. In the field of behavior it has appeared in its most extreme form in connection with the interpretation of the activities of the lower organisms. Here it is found in significant association with the method of trial.

The method of trial was first used in this field as a measure of the learning capacity of the higher animals. As such it has been eminently successful. In the obscure and baffling field of psychology it has encouraged the establishment of objective standards and the prosecution of vigorously scientific investigation. With its extension to the behavior of organisms in general, certain difficulties have arisen that have more frequently been subjects of dispute than sources of common understanding. Let me illustrate.

An interesting parallel to the learning process by which a cat is taught to escape from a puzzle box is the behavior of *Paramecium* in the presence of an obstruction in its path. The unsuccessful trials that accompany the learning process of the cat are represented in *Paramecium* by the motor reflexes that follow contact with the obstacle. These reflexes are the means by which the organism is adjusted to the situation. Passing the obstruction is evidence of successful adjustment.

To what extent is the behavior of *Paramecium* a key to the behavior of organisms in general, especially to that peculiar type in many of the lower organisms that is characterized by the direction of the reaction with reference to the source of stimulation? Is the motor reflex an essential factor in tropic responses?

IV

Of the answers which have been given to these questions, the affirmative alone is of present concern. According to this view, the final orientation of a phototropic organism to light is selected from among several positions occupied at random. Not only are individual responses the material for selection, but those individuals also whose initial responses are especially favorable to the rapid attainment of success; that is, the fit survive.

Now there can be no more doubt of the development of types of behavior with the aid of selection than the development of structural variations with similar aid—and no less. Scanty and uncertain as is the experimental evidence for natural selection, I do not wish to deny that it may have had large influence in organic evolution of whatever kind.

This is far from agreeing, however, that the precise responses of organisms to what for the sake of brevity may be called directive stimuli, have been effected, in all or in most cases by selection, whether of individual reactions or of individuals themselves. On the contrary, evidence is accumulating in favor of the view that organisms respond typically without trials; that what have been called, by a figure of speech, trials, are actually definite responses to stimuli that are neglected by the observer; that behavior is the resultant of many stimuli of which the directive stimulus is but one; that, in fact, the tropic response is rigidly determined as to direction by factors which complete analysis may be expected in all cases to bring to light.

V

The serious difficulty with a thoroughgoing application of selection theory to behavior is that it so emphasizes certain types of reaction as to divert attention from others, especially from the analysis of those physiological states on which it is generally recognized behavior depends. Nothing illustrates this fact more clearly than the criterion of stimulation that was introduced into studies of behavior with the method of trial.

Let us return again to *Paramecium*. How shall we determine when this organism is under stimulation? It is obvious that our criterion will depend on our reason for ascertaining the fact. If we are interested primarily with selection among such motor reflexes as *Paramecium* executes upon contact with obstructions, a sufficient criterion for our purpose might well be the reflex itself, however pronounced, that would bring the organism into a recognizably new position with reference to the source of stimulation. And it would continue to be sufficient regardless of the agency of stimulation—whether contact or chemical, light, gravity, galvanic electricity—provided only that the motive for it remained the same. It has been insisted, indeed, that in the orientation of the micro-organism *Euglena* to light, its swervings from the original path are typical evidences of stimulation, being regarded, in fact, as motor reflexes.

It follows naturally from such a criterion that when organisms such as *Paramecium* and *Euglena*, pursue unswervingly a direct course, they are in an unstimulated condition. That this conception, which is entirely compatible with the motive from which it springs, is quite useless in physiological analysis, will not be difficult to show, if it is perhaps not already apparent.

It is characteristic of the reaction of *Paramecium* to a continuous galvanic current that it moves toward the cathode, or anode, as the case may be, along a line of force, under very obvious compulsion. From beginning to end of its course toward the cathode, for instance, the cilia at the cathodal end of the organism beat constantly in a direction the reverse of that in which they beat when swimming freely in the absence of the galvanic current. It is as obvious that they are being subjected to constant stimulation as it is that the organism maintains a constant course. How can such behavior be reconciled with the criterion of stimulation established for the use of the selectionist?

It cannot. But the difficulty may be composed by disregarding it; by asserting, in fact, that since galvanic electricity has never been experienced by *Paramecium* in a state of nature; since it has never either directly or indirectly provided material for selection; the galvano-tropic response is of no serious importance to the student of behavior who is busy with problems of genesis and survival.

Such a procedure avoids still another embarrassment; namely, the radical modification of the definition of stimulus that served well enough for the reactions of various organisms to sudden changes in the intensity of what may be called the stimulating medium. When *Stentor* passes from a shaded to a brightly illuminated area, it executes a motor reflex at the boundary of the shadow much as it would react to contact with a solid object. Reactions of this type have long been recognized and ascribed to a capacity of the organism commonly known as *unterschieds empfindlichkeit* or differential sensibility. They are of the nature of trigger effects, depending on the release of internal energy by a sudden change of potential in the stimulating medium. It is this change in potential or intensity rather than any addition of energy from without that represents the stimulus in all such cases. Can this conception of stimulus be applied to tropic responses as well ?

It is noteworthy that probably the most typical reactions of this type are executed by various organisms when subjected to sudden changes of potential in the galvanic current. *Paramecium*, for instance, responds to the making and breaking of the current by characteristic motor reflexes. And this is quite regardless of the fact that the galvanic current is unknown to *Paramecium* in a state of nature and could have played no part in the evolution of its behavior.

The responses of *Paramecium* to the galvanic current are, accordingly, of two types. And these it is quite impossible to reduce to the common denominator of the motor reflex. How is it then with the responses of photosensitive organisms to light, which fall similarly into two groups ? For light, unlike the galvanic current, belongs to the world of nature. It is only exceptionally a laboratory product. Hence its influence on the behavior of organisms cannot be disregarded. Can these two types be reduced to one whose key is the motor reflex in one form or another ? Are the remarkably direct and precise turning movements that characterize tropic reactions resultants of the selection of random movements of this type ? Or are they compelled by the constant application of energy, as is *Paramecium* in the constant galvanic current ?

There can be no doubt that a successful attempt to resolve the difference here presented, in terms of a single fundamental factor, would greatly simplify the problem. But, assuming the existence of such a factor, the view that its application to tropic responses would involve selection of random movements does not square with the fact that various organisms, among them *Euglena*, the earthworm (*Allolobophora*), the sow bug (*Porcellio*), and house fly larvae have exhibited unmistakable evidence of responding to light by reactions whose direction can be definitely *predicted.*

VI

The crux of the matter, however, for the physiologist, lies in the third question. Here the problem appears under a purely physiological guise. It is formulated in physiological terms. It invites attack from the side of physics and chemistry. It suggests a measure of energy transformations.

If there is a definite relation between the application of energy to an organism and its behavior, it might be expected to appear in an examination of the evidence for constant stimulation. For the sake of brevity but a few of the recent contributions to this end will be considered, including certain results as yet unpublished. They have been chosen so as to outline the gradual emergence of demonstrable fact from a crowd of observations whose real significance could only be surmised in the absence of later experimentation. We may begin with the phototropic behavior of *Euglena.*

It has frequently been observed that when *Euglena* is exposed to light from two sources the direction of its locomotion may be most delicately adjusted to their intensity as well as to their position, and experimentally controlled with remarkable precision by modifying these two factors. These facts have been interpreted in various ways. To some they strongly suggest, though they do not demonstrate, the presence of constant stimulation.

Two years ago, experiments that involved the most careful and detailed observations of the behavior of *Euglena* that have ever been published, led Bancroft to the conclusion that the reactions of this organism to light are not only of two distinct types but governed by two distinct mechanisms. Of especial significance was the observation, which has been confirmed in my own laboratory, that when *Euglena* swims directly toward the source of light in its characteristic spiral path, the width of the spiral changes with the distance of the organism from the light. In this orientation, the photosensitive area is presented constantly to the source of light, not intermittently as would be the case were the light falling on the organism from one side. Constant illumination produces a constant response. The variation of the width of the spiral with the intensity of the light thus constantly playing upon the photosensitive area leaves no room to doubt that the organism is as surely in a condition of constant stimulation as is *Paramecium* when exposed to a constant galvanic current. Its orientation is forced.

Can the relation between the photic energy applied to the organism and the reaction of the latter be expressed in quantitative terms? Though this has not yet been accomplished for *Euglena*, experiments have shown that the relation can be expressed for several other organisms in terms of the law originally offered by Bunsen and Roscoe as a formulation of the effect produced by light upon silver chloride. According to this law, stated in more general terms than those originally employed, the effect of the light radiation is proportional to the product of the intensity of the light and its duration, that is, to the total amount of photic energy supplied.

The first application of the Bunsen-Roscoe law to biological phenomena appears to have been made by the plant physiologist Blaauw. The results of his investigations on oat seedlings (*Avena*) and a fungus (*Phycomyces*) published in 1909, are in striking conformity with the theoretical expectation. It will not be possible here to consider either the details of his experiments or their technic. It must suffice to say that in a series of twenty-six experiments on *Avena*, he varied the duration of the light from 1-1000 of a second to 43 hours, and its intensity in inverse ratio so that the energy delivered should be a constant quantity; and that in spite of this enormous range in the values of these factors, the extreme experimental variation from the average among the entire twenty-six measurements, was but 28 per cent. When it is remembered that the response of an organism to a given stimulus is necessarily complicated by the influence of various other stimuli whose effects may not even be recognized, much less accurately determined, I believe we shall be willing to admit that Blaauw's experimental results demonstrate the applicability of the Bunsen-Roscoe law to the phototropism of plants.

Later experiments have shown the applicability of this law to the phototropism of animals also. Loeb has obtained evidence of its existence in a hybroid (*Eudendrium*). Ewald has found it to apply to the eye movements of *Daphnia* under appropriate stimulation. According to Patten there is evidence of it in the behavior of blowflies. And one of my students, G. P. Hays, appears to have demonstrated that the phototropism of the fruit fly *Drosophila* conforms to it also. This case will be briefly sketched.

The imagoes of *Drosophila* are positively phototropic. The method of experimentation consisted essentially in subjecting a given number confined in a large test tube, to diffused light from a source whose area could be readily controlled by diaphragms. The flies were first aggregated at the end of the tube away from the light, and then exposed to it, from darkness, for a given number of seconds. The number of flies entering during that time the fifth of the tube which lay nearest the light was adopted as the criterion of the effect of the light. *Drosophila* is so sensitive to light that it was found necessary to use very low intensities in order that the responses obtained at different exposures might be determined with a sufficient degree of accuracy.

Five intensities, multiples of 1, were used, with exposures, varying from 16 to 80 seconds, calculated to deliver the same quantity of photic energy in all five cases. Every day ten trials were made at each intensity, and the average number of flies affected was computed. This was repeated on five successive days with five different sets of flies and the results averaged. These averages agree excellently with Blaauw's figures, varying from 1.44 to 2.1. Under the conditions, this is a satisfactorily constant result. I do not see how it can be interpreted on any theory that neglects the quantity of photic energy involved.

If it appears from the facts that have been thus hastily summarized that tropisms are not interpretable in terms of random movement and selection processes, must we then conclude that they possess no fundamental characteristics in common with reactions of the non-directive type ? By no means. The essential relationship of these superficially different kinds of reflexes is to be found in the physiological processes that they represent, processes that are evident also in the phenomena of growth, development, differentiation, and all other manifestations of life. As physiological reflexes, tropisms exercise their fascination for the general physiologist, because they offer certain peculiarly favorable opportunities for physiological analysis. And I think we may say that all reflexes must be thus analyzed if they are to be subject to the control that is demanded by human beings for whom conduct is the one problem of perennial interest and concern.

NOTES ON THE FEEDING BEHAVIOR AND OVIPOSITION OF A CAPTIVE AMERICAN FALSE SPIDER

(*Eremobates formicaria* Koch)

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INTRODUCTION

Eremobates formicaria is a false-spider, a member of a peculiar group of Arachnids (*Solpugidae*), in which there is a ten-jointed abdomen and a segmented thorax, and in which the first pair of legs is modified to serve as feelers, so that each individual seems to have three pairs of legs and two pairs of pedipalpi. These are rare invertebrates and are found only in the warmer parts of the world. In our country they occur only in the southern and western portions. We know almost nothing about the habits of our indigenous forms. During the past quarter of a century no original observations upon the behavior of our American forms have appeared. All that has been published upon their activities prior to that time has been condensed by Putnam (16) in the following quotation:—

> "Regarding the habits of the American Solpugidae comparatively little is known. I have myself collected five individuals of *D. pallipes* in different parts of Colorado. They were always found, one at a time, in a small cavity in the earth, under a stone or 'buffalo chip.' No other animal life was visible in their vicinity, and they appeared to be quite pugnacious. In my haste to transfer them to alcohol I failed to make any particular observations upon their behavior and mode of life.
>
> "At the meeting of the Academy of Natural Sciences of Philadelphia, held November 7th, 1871, Prof. Cope stated, on the authority of Dr. Gerhung, that it (*pallipes*) was common in (Denver) houses, and was an enemy and destroyer of the *Cimex lectularius* (bed-bug). In captivity it showed a preference for them as food, and crushed them in its short chelae preliminary to sucking their juices.
>
> "Upon sending me two specimens of *D. Californicus*, Mr. D. Cleveland wrote that they were found at San Diego, in October, under a board near together in a small, funnel-shaped sand hole, with nothing else near them in the way of life, and that they were belligerent. Rev. Green writes that one morning at Silver City, New Mexico, he found a small *Galeodes* dead and half buried away on the top of his candle. On another occasion, while lying on his bed one very hot night, a large *Galeodes* ran across his body and down one of his legs, but escaped before he could capture it. Regarding the Texas species (*D. sulfurea* and *C. geniculata*), Mr. G. W. Belfrage writes as follows: 'They are true nocturnal species, running

with great activity about houses at night, and are attracted by the light, and sometimes to sugared trees. They are rare, but appear more common in rainy seasons, and only in dark and damp nights. They are probably solitary, and although I have examined everything in the locality where they have been taken for years, I have never found a single one in the day time. When attacked they raise and swing their formidable palpi and show fight, but they are perfectly harmless.'

"From Guanajuato, Mexico, Dr. Eugene Duges writes as follows: 'Here there is a *Gluvia* which the vulgar call *Genisaro*, and make out to be excessively venomous, which it is not the least in the world.'

"Dr. Edward Palmer, speaking of the specimens collected by him in Mexico, says: 'The *Solpuga* marked San Louis Potosi was running in a garden, the one from Bledos was taken out of my bed in the night, while the other was found under a piece of volcanic rock.'

"Dr. R. A. Phillippi, writing from Santiago, Chili, and speaking of the two species described by Gervais (*C. morsicans* and *M. variegata*) says: 'They are very common in the streets of Santiago, running with great swiftness in the sun, so that they are called 'aranas del sol,' (spiders of the sun); their bite is said to be very painful, but I know of no personal experience of my friend or my own, unless one case when a young daughter of mine having been bitten in the finger, experienced severe pain, fever, and had the whole forearm swollen for two days, but I do not know whether she was bitten by a *Galeodes* or by *Lathrodectus formidabilia*.'"

Meager as these accounts are, so far as I have been able to ascertain, they contain all of the first-hand knowledge we have of the habits of the American false-spiders.

THE BURROW*

Knowing that the female of an Indian false-spider (17, 11) burrows into the ground to lay her eggs, I confined my captive in a glass jar containing about four inches of dry, compact soil. Although it was broad daylight, she proceeded at once to excavate a burrow. With her jaws (chelicerae) and her second pair of legs, she dug out the soil and scraped it backwards. When a pile of dirt had been thus accumulated beneath her body, she shoved it away in the following manner. The ventral surface of each chelicera is flat and on a level with the equally flat ventral surface of the thorax (Figs. 2 and 3). The jaws are on the upper anterior (dorso-anterior) portion of each chelicera (Fig. 1) and the lower anterior (ventro-anterior) surface of each chelicera is almost truncate (Fig. 3). With the body appressed against the ground and the ventro-anterior surface of the chelicerae pressing against the pile of dirt and the blades of her jaws above it, the solpugid moved forward, pushing the dirt ahead of her. These movements were repeated over and over again until the burrow had been completed.

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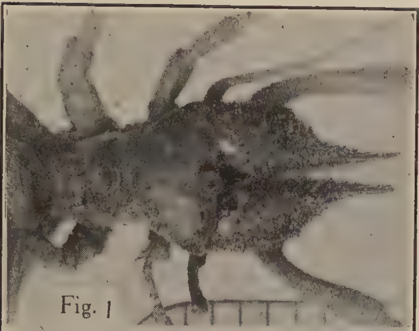
*The false spider which supplied the data for this paper was sent to me alive, from New Mexico, by Mrs. Maud Tanter.

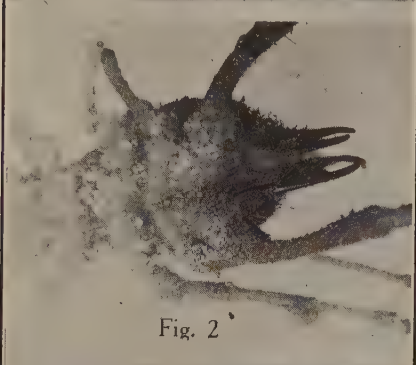
The floor of the completed burrow sloped inward, forming an inclined plane of about thirty degrees. Having completed her burrow she plugged the opening with soil and remained therein the remainder of the day. This false-spider is nocturnal in her habits. Each night she constructed a new burrow, in the manner mentioned above; but there were variations in both the direction of the burrow and its length. Sometimes, after reaching the bottom of the jar, the cavity turns and continues upward almost to the surface; at other times, by means of an elbow, the burrow is extended in some other direction. At night, on leaving the burrow to forage, she usually closes the mouth with dirt. In about seventy per cent of the cases the burrow was closed during the day. In its habit of excavating a new burrow each night, our New Mexican *Eremobates formicaria* differs from the Indian species of *Galeodes* studied by Hutton (11), which occupies the same burrow throughout the breeding season.

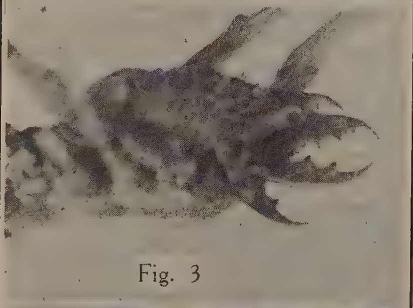
FEEDING ACTIVITIES

Daily a large number of live insects were placed in the jar of this solpugid. At night, after closing her burrow, she would proceed to slay and eat. She is, indeed, voracious; feeding ravenously and almost indiscriminately upon small moths, small beetles, nymphal locusts, small locusts and grasshoppers, lace-wing flies, crickets, small bugs, caterpillars, flies, gnats, etc. Some she chases down; others she captures by resting quietly until they come within striking distance of her jaws. On the evening of July 30th, between half past nine and half past ten, she captured and devoured four moths, four small beetles, one lace-wing fly and several gnats. When I left at half past ten, she was lying in wait for other prey. With the exceptions mentioned later on, this greediness was exhibited nightly.

In 1843, Hutton (11), in discussing a large false-spider (*Galeodes*) which he captured in India, says: "This species is extremely voracious, feeding at night upon beetles, flies and even large lizards. * * * A lizard three inches long, exclusive of the tail, was entirely devoured. * * * The only parts uneaten were the jaws and parts of the skin." J. H. Comstock (6) doubts the correctness of this statement. In 1911 he replies: "Captain Hutton states distinctly that the *Galeodes* observed by him con-







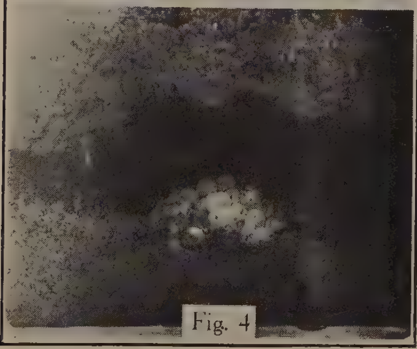


FIG. 1. Dorsal view of the cephalothorax of the false-spider *Eremobates formicaria*, Koch. Each division of the scale shown at the bottom is one millimeter.

FIG. 2. Ventral view of the cephalothorax of the false-spider *Eremobates formicaria*, Koch. The scale is the same as in figure 1.

FIG. 3. Lateral view of the cephalothorax of the false-spider *Eremobates formicaria*, Koch. The scale is the same as in figure 1.

FIG. 4. Eggs of the false-spider *Eremobates formicaria*, Koch, photographed twenty-four hours after they were laid.

sumed an entire lizard except the jaws and parts of the skin. Other instances in which solpugids are supposed to have eaten their prey are given by Rev. J. J. Wood, in his ' Natural History Illustrated,' and quoted by Murray. Still it is believed that solpugids take only liquid food, which they suck from the bodies of their victims."

Since the jar in which my solpugid was confined is only five inches in diameter, frequently the arachnid captured her food near enough to the side of the jar for me to focus my hand lens upon her jaws. Evening after evening, magnifying glass in hand, I have watched those jaws while the false-spider devoured insect after insect. And then, when the arachnid had cast the remains aside, I have fished them out with a crooked wire. Our *Eremobates formicaria* is not a mere imbiber of juices; she consumes all of her victims except the hard chitin.

Her first pair of large appendages are powerful chelae, each blade of which is armed with stout teeth (Fig. 3). These chelicerae are so articulated to the head that, as the blades move dorso-ventrally like those of scissors, the chelicerae move forward and back with a saw-like movement. While the right chelicera is moving forward the left is moving backward. When a small insect is captured by the chelicerae, this scissors-saw-like movement of the jaws soon reduces it to a shapeless mass of chitin, while the contents of its body are being consumed. When the *Eremobates formicaria* encounters a large insect, it usually grabs it, on the ventral side, just back of the head. Once the jaws have secured a hold, the creature is usually doomed. The insect may squirm and struggle and jump, but the false-spider retains its hold. I have seen a locust jump back and forth across the jar several times without getting rid of its antagonist. In a comparatively short time the scissors-saw-like movements of the jaws make a breech in the integument of the victim. If the thorax is large enough, the jaws are inserted and their scissors-saw-like movements enable the arachnid to soon pulpify and devour much of the contents of the body. After the removal of all of the contents that can be secured in this manner, the lower blade of each jaw is placed on the outside and the upper blade on the inside of the body of the victim, and the scissors-saw-like movements continue. At the same time the carcass is moved from side to side and back until the chitin has been scraped clean. When the thorax is too small for the jaws to be inserted, from the beginning, the lower blade of each jaw is placed on the outside and the upper on the inside of the body. After the body has been disposed of, the fleshy parts of the legs and even the bases of the wings are subjected to these scissors-saw-like movements of the jaws and passed from side to side between them, until all edible parts have been removed. If the false-spider is not disturbed while eating the carcass left behind is usually nothing but a shapeless mass of chitin. Even when disturbed the result is often the same.

Normally this false-spider feeds only on living prey. With dead insects on all sides, I have seen it rest quietly for more than an hour, waiting for living prey. However, it is possible to induce it to eat recently killed insects, if they are properly manipulated. Two large crickets that had been dead about an hour were placed in the jar with the solpugid. One of these was manipulated in such a manner that it moved about and occasionally touched the false-spider. The movements did not resemble in the least those of a living cricket; they were simply jerky and somewhat gentle. Finally the false-spider grabbed the cricket by its posterior end (which end was moving forward) and devoured it in the manner mentioned above. In due time nothing was left but one leg and a shapeless mass of chitin. Although she came in contact with the other dead cricket several times, never once did she even attempt to eat it.

I found two living things that my specimen would not eat: hairy caterpillars and spiders. When first confronted with a hairy caterpillar, she sprang to the attack, snapping viciously. At each snap she secured a jaw full of hairs, but the larva was unhurt. She then wiped her chelicerae on the soil, as though trying to clean them. After the first few nights she no longer snapped at hairy caterpillars, but, when they came near her, she would back or rush away. Along with the insects obtained by sweeping I placed live spiders in the jar. She never touched one of them in my presence. Each morning I found practically all of the spiders alive. Whether this immunity of the spiders is due to their elusiveness or to an inherited bias against them on the part of the solpugid is uncertain.

Although these false-spiders are nocturnal in their habits and spend much of the day asleep—reclining on either the side, the back, or the sternum—if food strays near them, they rise, slay and eat. Occasionally the burrow was left open in the day-time. On such occasions, on dumping live insects into the jar, some were sure to fall into the burrow. Immediately the false-spider would begin to eat.

THE EGGS

On the twenty-sixth of July the burrow of this false-spider was built against the glass of the jar in such a manner that practically all of the interior was visible. That evening the solpugid did not come out to forage, and on the following morning she was resting quietly in the bottom of the burrow. Sometime during the day she laid a batch of milk-white, spherical eggs (Fig. 4). Each egg was about 1.7 millimeters in diameter. At six on the evening of the twenty-seventh the eggs were in the bottom of the burrow and the false-spider was resting about halfway between them and the mouth of the burrow. At nine that evening she was busy plugging the mouth of the burrow with soil, taking pains not to include dead insects. Off and on several dead moths got into the dirt she was shoving into the burrow. Each time she caught the moth in her chelicerae and dragged it, backwards, away from the burrow. Later in the night, after having gluttonized, she excavated a new burrow in another part of the jar. For the next two weeks she excavated a new burrow each night.

On August the eighth no part of her burrow was exposed, hence it was impossible to see what was transpiring inside. Up to a few minutes after nine that evening she had not appeared on the surface. This was past her usual time of appearing, and since for several days I had been expecting her to lay again, I began to wonder if she were ovipositing. Little by little the soil was carefully removed until the solpugid was exposed in her burrow. She had not laid. Soon after this disturbance she crawled to the surface and moved about sluggishly; but did not feed. I watched her until about eleven o'clock and then went to bed. By the next morning she had oviposited. There were a few milk-white, spherical eggs in the bottom of an exceptionally short burrow; and many more were strewn on the ground near to and on its closed mouth. In the course of a few days a few of these eggs had turned yellow and had begun to shrivel into angular shapes.

The night following the laying of these eggs, the false-spider came to the surface and fed. The next morning she was resting in a depression of the ground. For several nights thereafter she fed as usual; but did not construct any more burrows. She spent the day in some depression of the ground. On the night of the twelfth she fed heartily; on the morning of the thirteenth she was dead.

In both color and size the eggs of our American *Eremobates formicaria* are similar to those of the Indian *Galeodes* studied by Hutton (11, 15), but the habits of the mothers are not identical. After laying her eggs in the burrow, the Indian *Galeodes* rests quietly among them. After they have hatched, she guards the burrow and prevents any intruder from harming her children. Our American *Eremobates formicaria* digs a new burrow each night, and lays a second batch of eggs before the first has had time to hatch. Nothing in her behavior suggests that she guards her young from danger.

CONCLUSIONS

1. The American *Eremobates formicaria* constructs its burrow in the same manner as does the Indian *Galeodes* studied by Hutton; but instead of using a common burrow throughout the breeding season, the female constructs a new one almost every night.

2. The female of this species is nocturnal in her habits, remaining in her burrow all day. On retiring to her burrow and in departing therefrom, she usually closes the mouth with dirt.

3. She feeds voraciously upon a large variety of insects, which she secures by chasing them, or by lying in wait until they come to within striking distance of her powerful jaws.

4. Like the Indian *Galeodes* studied by Hutton, this false-spider eats solid food. Aided by the scissors-saw-like movements of her powerful jaws she pulpifies and devours all parts of the captured insects except the chitin.

5. Normally this species feeds upon live insects; but she may be enticed to feed upon recently killed insects that are artificially induced to move. Ability to move seems the main

attribute by means of which she distinguishes the living from the not-living.

6. Like the Indian *Galeodes* she deposits her milk-white, spherical eggs in the bottom of a burrow; unlike the Indian species she closes the mouth of the burrow and leaves the eggs to their fate.

7. She lays, at intervals, more than one batch of eggs a season.

8. Judging from the mother's behavior in captivity, the young are allowed to shift for themselves; the Indian *Galeodes* described by Hutton protects her young.

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* In this list an attempt has been made to include all papers that have been written upon the habits and life-history of American Solpugidae; and papers on the habits of foreign forms that have appeared during the past twenty-five years. References to earlier papers will be found in Putnam's (16) article.

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